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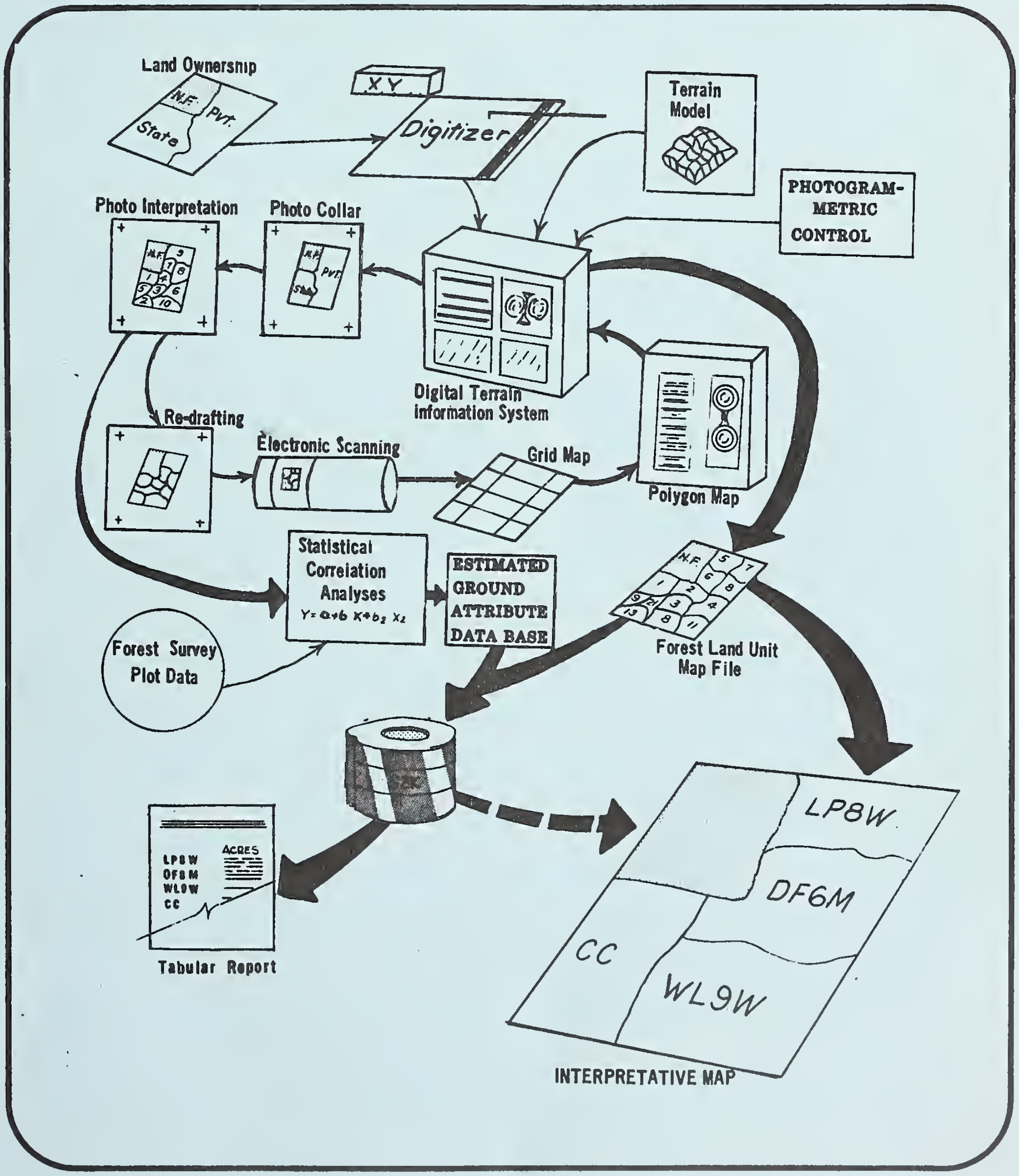
Montana Timber - Water Cooperative Study

Automated Systematic Method for Forest Land Classification & Mapping



MONTANA TIMBER-WATER COOPERATIVE STUDY

AUTOMATED SYSTEMATIC METHOD

for

FOREST LAND CLASSIFICATION AND MAPPING

Prepared By

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Soil Conservation Service
Economic Research Service
Forest Service
and
State of Montana

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Others who contributed to the study are:

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Gary Brown	Montana Department of Lands, Division of Forestry	Study Objectives
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SUMMARY

This study has demonstrated that automated methods for forest land mapping can be executed in an operational environment and that they are cost effective. Electronic scanning and associated computer processing have shown to be more efficient than manual digitizing for input of complicated graphic documents into a computerized geographic information system. Similarly, an automated photo-to-map transfer of photointerpreted data appears to provide comparable and more versatile products than traditional methods and at less cost.

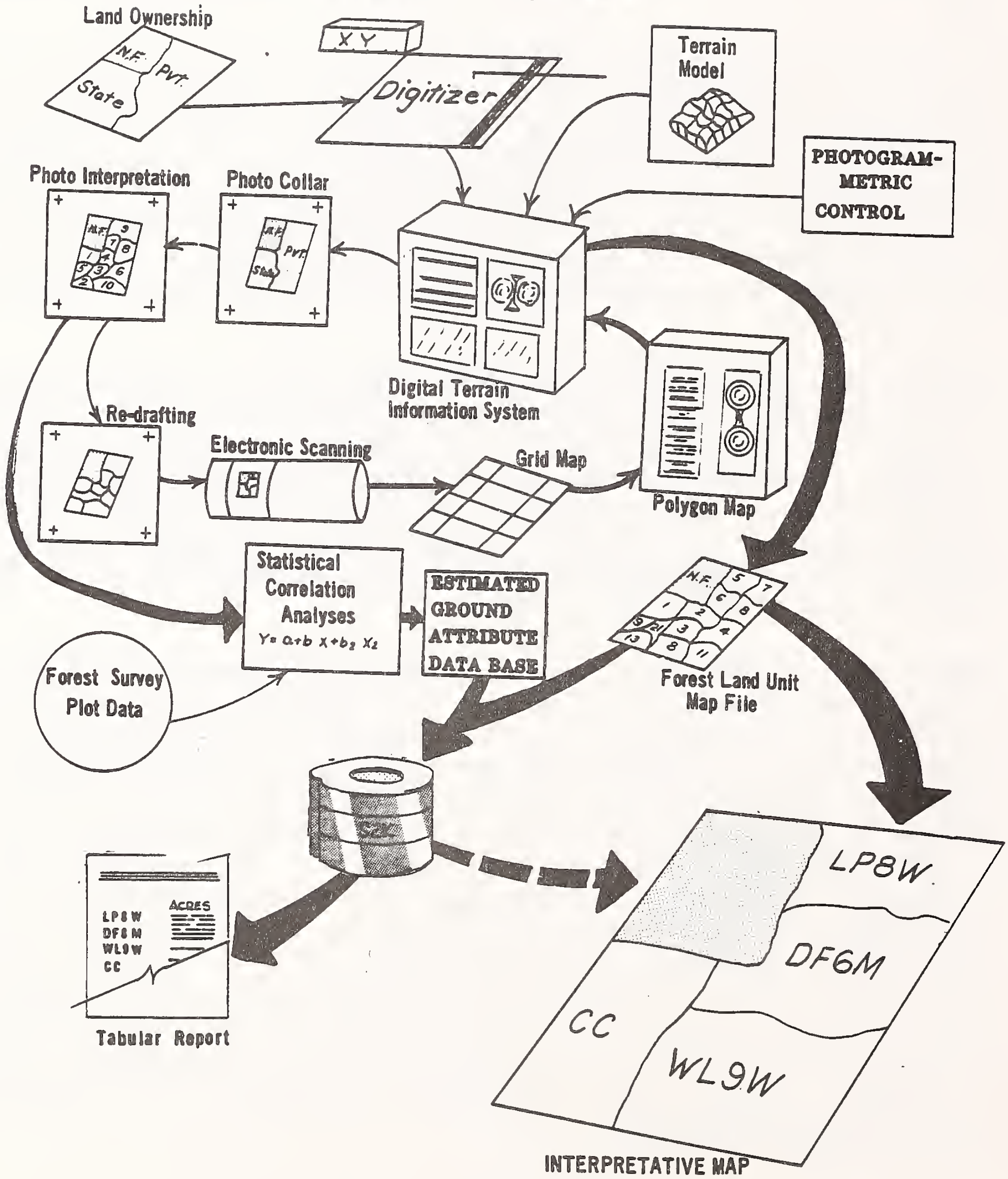
The big pay off of these techniques is not, however, just cost savings over traditional manual methods. By providing an efficient means for building a forest land information system, improvements in forest land management can be expected. Forest stand characteristics can be quickly queried and displayed in a multitude of ways facilitating forest inventory and planning. This ability also permits rapid update of stand conditions and road developments. The integration of forest stands, roads, and terrain into a composite data base should also help improve stand management prescription.

The system presented is not without difficulties. This includes the need to access specialized equipment, i.e., electronic scanner, main-frame computer and computer controlled plotter, and photogrammetric control data. Although this system requires less total time than traditional manual methods, planning and sufficient lead time is required to complete the numerous separate operations. A high degree of managerial control is also essential since the computer systems used (RID*POLY, DTIS II, System 2000, etc.) are not formally integrated.

Figure 1 illustrates the mapping system pilot tested on 1.5 million acres in west-central Montana. Landownership boundaries, digitized from existing land status maps, and photogrammetric control are input to the Digital Terrain Information System (DTIS-II) as currently operating at the USDA, Fort Collins Computer Center. The ownership and 7.5-minute quad boundaries are photogrammetrically transformed to overlays in the perspective of quad-centered 1:80,000 scale photography. The overlays provide a guide for photointerpretation and edge-matching between photos. The diapositive stereo-model is photointerpreted within the overlay boundaries to delineate and classify individual Forest Land Units (FLU's). The FLU boundaries are then traced from the diapositive and automatically digitized using an electronic scanner. Next, the digitized FLU's are processed into closed polygons using RID*POLY. The closed polygons are processed through DTIS-II to produce a computer drawn FLU map as an overlay to the 1:24,000 scale 7.5-minute quadrangle map. The area and ground coordinates of each FLU are also calculated by DTIS.

Each delineated FLU is sequentially numbered and its photointerpreted (PI) characteristics coded on a separate form. Ground plot information from the Montana Forest Survey (MFS) is identified within respective FLU's. These data are statistically analyzed to derive equations for predicting from the PI variables, selected ground attributes, such as, volume, growth, yield capability, stocking, habitat type, forest type, etc., for each mapped FLU. The PI characteristics, predicted attributes, acreage and

FIGURE 1 The Mapping System



ground coordinates for each FLU are loaded into a System 2000 (S2K) data base management system. S2K data base queries and accompanying DTIS computer generated graphics provide stratified listings and interpreted attribute maps. Cost for this mapping system was approximately 10¢/acre of which the photointerpretation, statistical correlation, and map file each amounted to approximately one-third of the cost.

Contact the U.S. Forest Service, Northern Regional Office, P.O. Box 7669, Missoula, Montana 59807, if additional information is desired concerning this project.

I. INTRODUCTION

INTRODUCTION

It seems foresters have always used maps as aids in locating forest stands, roads and other terrain features. With greater demands being placed on natural resources the need for identifying discrete forest units for land allocation and intensive management practices makes the mapping and characterization of Forest Land Units all the more critical for responsible land stewardship.

Topographic maps are extensively used by foresters for locating property boundaries and proposed roads and for evaluating terrain constraints on logging and other management activities. Over the years stand maps identifying tree species and timber volumes, have also been prepared for most forest areas. More recently maps have been prepared showing units of land having similar productive capabilities regardless of current stand conditions. Habitat type maps, ecological land unit maps, land type maps, and biophysical unit maps are examples of such capability unit maps. The combination of stand maps with capability unit maps provides a tool for not only the inventory of existing forest conditions, but also for continual intensive management of Forest Land Units. By supplying information for silvicultural prescriptions and by providing a data base for tracking forest practices and stand growth over time, Forest Land Unit maps can be a valuable tool to both the on-the-ground forester and the forest administrator.

Because of the large amount of land managed by most public and private foresters, aerial photographs have become the primary tool for mapping forest conditions and for map updating. Tree species and often tree size are interpreted directly from the air photo, while capability units are usually extrapolated from known locations using stereo interpretation. Because most roads are clearly visible, even on high altitude photographs (1:80,000 scales), new roads are transferred either manually or with the aid of stereo-plotters for map update. In many cases air photos often replace or supplement forest maps for on-the-ground investigations. With the addition of land survey lines or property boundaries, air photos can become the base for laying out timber sales or identifying stand boundaries for timber management activities.

Because of the need for better data coordination and processing tools, an automated system was envisioned to enable land managers to expand ground inventories to mapped Forest Land Units and to evaluate and display tabular and mapped resource information for project planning through a versatile computer system.

Problem and Needs

State and private forest lands in Montana form a significant part of the State's total forest resource base. Current data show 6.2 million acres in State and Private (S&P) ownership and 16.4 million acres of federal forest land (USDA-FS 1977). Timber harvests from S&P lands account for 463 MBF or 52 percent of Montana's current timber harvest (Hearst 1981). The S&P forests also provide a significant land base for water, forage, wildlife, mineral production and recreational use.

The study was motivated by the need for mapped S&P forest land characteristics to assist in identifying management opportunities and/or constraints and to provide a readily available data base for forest resource planning and decisionmaking. The need for a computer driven geographic information system is not unique to State and private forest land interests.

The Montana Forest Survey (MFS) is an extensive inventory of S&P forest lands. The survey does not provide locational data at the level useful for local management decisions. The need to expand the MFS data to mapped Forest Land Units was expressed by the study sponsor.

Request for Study

The Montana Department of Natural Resources and Conservation (DNRC) requested a study be conducted to; (1) provide locational forest stand data and maps of State and private forest lands in Montana to improve assistance in forest resource planning and implementation, (2) to identify changes in watershed conditions that will occur from harvesting on forested land, and (3) to determine opportunities and needs for erosion reduction practices.

Authority

The Montana Timber-Water Cooperative Study was authorized in October 1980 under Section 6 of the Watershed Protection and Flood Prevention Act of the 83rd Congress (Public Law 566, as amended). The agencies cooperating in this study include the Soil Conservation Service, Economic Research Service, and Forest Service of the Department of Agriculture, and the Montana Department of Natural Resources and Conservation.

Study Objectives

This study originally covered two disciplines; (1) forestry (timber management) and (2) hydrology (water resource management). As the study progressed, empirical data of the appropriate accuracy was perceived not to be available for correlating hydrology parameters to the Forest Land Units being generated. A report titled "List of Selected References: Erosion and Sediment Publications" is available as a product of the search for usable hydrology information.

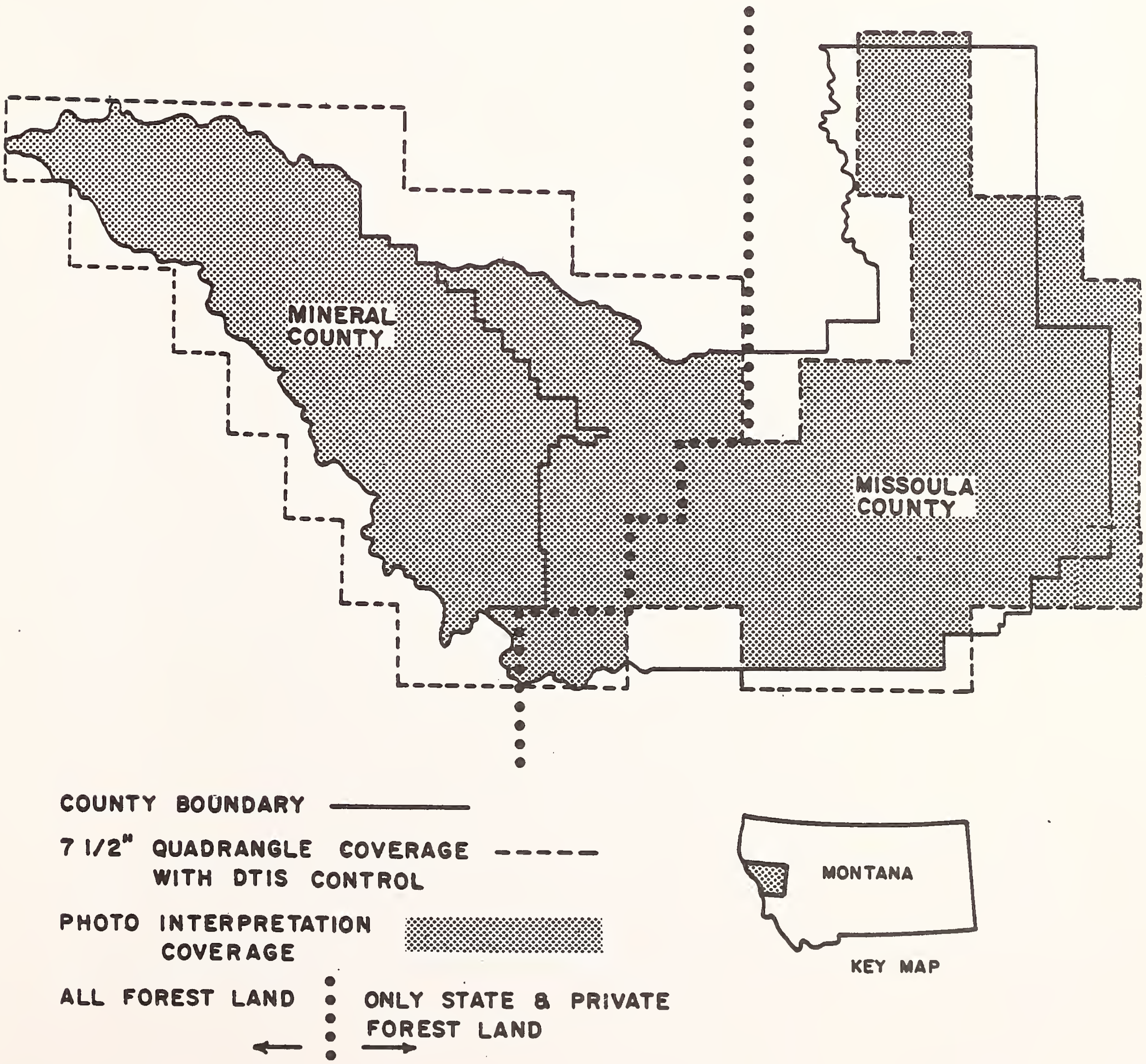
Sponsor support was therefore withdrawn for the complete study. A modified project was then formulated to demonstrate progressive forest land classification, mapping, and timber resource evaluation techniques. This modified project was an extension of the initial developmental stage of the study. The location of the project area is shown in Figure 2.

The modified study required; (1) completing the development of photointerpretation and mapping methods, (2) evaluating photointerpreted characteristics for expanding ground sample data to unsampled mapping units, and (3) documenting the results including sample products illustrating types of tabular and mapped information accessible through the system.

FIGURE 2

LOCATION OF DEMONSTRATION PROJECT

Montana Timber - Water Cooperative Study



Purpose of Report

This report documents the procedures used to classify and map forest land in west-central Montana and to expand an extensive forest inventory to mapped Forest Land Units. A workable automated system is presented that can be compared with other geographic information gathering systems for versatility, usefulness, accuracy and cost. The resource manager will be challenged to consider the capabilities of this or similar technology in resource inventory planning and project design activities.

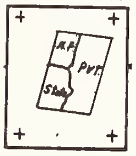
Technical reports by Martin, and Martin and Cook (1983), describe in more detail the automated cartographic, statistical expansion, and forest land classification procedures used in this study.

II. PHOTOINTERPRETATION

PHOTOINTERPRETATION

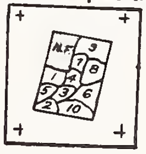
Aerial photos used in the study were 1:80,000 scale panchromatic (black and white) film transparencies (diapositives) having an effective area approximating a 7.5-minute quadrangle. A photo collar with landownership, jurisdictional, and quadrangle boundaries, drawn on it was traced onto this film transparency as a guide for the photointerpretation (PI).

Photo Collar



PI consisted of two steps; (1) delineation of Forest Land Units (FLU's), and (2) classification of each delineated FLU, using procedures developed by Martin and Gerlach (1981, A, B). In placing boundary lines the interpreter did not initially attempt to identify specific categories of PI variables, but rather sought to delineate observable tracts, homogeneous in terms of forest cover and topography. This work was conducted using a zoom-stereoscope having a magnification capability of 2.5 to 20 power. After FLU's had been delineated, the interpreter recorded the specific categories for each PI variable within each delineated tract on a separate coding form. Photointerpretation was conducted under specifications of Contract No. 53-0343-0-394. FLU description criteria are listed in the Appendix.

Photo Interpretation



Because the FLU's were quite small at photo scale, averaging 25 acres in size or about 0.15 inches square, traditional legend type annotations could not be made on the air photos. Therefore, a unique sequential number identified each delineated unit on the photograph. This unique number was also entered on a separate coding sheet which carried coded descriptions of photo-interpreted topographic and forest overstory characteristics and the ownership and political jurisdiction of each mapped unit. An annotated stereo-interpreted film transparency, with the photo collar superimposed, is shown in Figure 3.

The FLU's within the photo collar were then manually re-drafted onto scribe coat material to exclude extraneous detail for further processing, as described in Chapter III.

Re-drafting

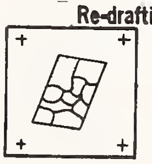


FIGURE 3 ANNOTATED FILM TRANSPARENCY WITH PHOTO COLLAR SUPERIMPOSED

III. MAPPING METHODS (AUTOMATED CARTOGRAPHY)

MAPPING METHODS (AUTOMATED CARTOGRAPHY)

BASIC PRINCIPLES

The automation of forest land mapping must address four general operations. These are; (1) photogrammetric control, (2) digital terrain modeling, (3) data entry, and (4) computer processing of geographic information. These operations are not unique to forest land mapping but are basic to almost all automated mapping projects.

Photogrammetric Control

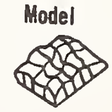
PHOTOGRAMMETRIC CONTROL

Photogrammetric control is a prerequisite for automating the transfer of identified features or interpreted delineations on an aerial photograph onto a map base. Control is also required for the inverse process, that is the drawing of map or survey features onto an air photo.

Differences in the relative imaged position between ground features from their actual true position is the primary difference between maps and aerial photographs. Features on maps can be readily and accurately measured with regard to areas and distances because the scale is constant across the map and because the portrayed map features are in their correct relative positions. On the other hand, areas and distances can be accurately measured on air photographs only when adjustments for camera orientation and relief displacements are made. Photogrammetric control is a prerequisite for computing these adjustments. The controlling of aerial photographs has become a highly refined science, routinely accomplished by most mapping agencies. Analytically developed photogrammetric control purchased from USGS was used for this project.

Digital Terrain Modeling

Terrain Model



The elevation of the land surface directly influences the position of images on the aerial photo. The elevation and the shape of the land surface is also important for the design and layout of roads and logging systems and for its influence on the ecology of an area.

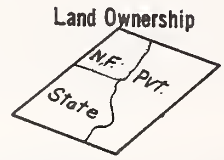
Like the topographic contour map, a terrain model is a representation of the shape and elevation of the land surface. Unlike a contour map, however, the terrain model is not a pictorial representation of the land, but rather, a mathematical representation. The value of the terrain model over a contour map is that a set of computer programmable commands can be used to access the elevation data, instead of using traditional manual techniques to extract terrain information from the mapped contours.

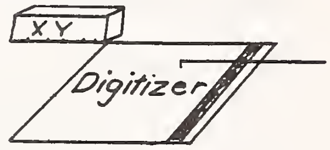
The importance of terrain models is rapidly becoming recognized. The Defense Mapping Agency (DMA) was the first to produce terrain models for extensive areas, and due to that effort, terrain models are available for all of the contiguous 48 states. DMA terrain models provide an elevation point every 200 feet horizontally with a vertical accuracy about 150 feet. In recent years, the USGS has initiated a program to provide higher resolution terrain models.

These digital elevation models (DEM's) have been produced for about 20 percent of the lower 48 States and provide an elevation point every 100 feet with a vertical accuracy of 20 feet or better. Incomplete coverage of DEM's for the study area necessitated the use of predominately DMA terrain models.

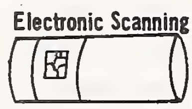
Data Entry

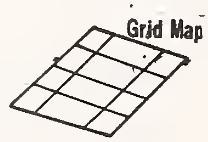
Landownership and political jurisdiction boundaries were identified and plotted on USGS 7.5-minute topographic quadrangles. The ownership, political and quadrangle boundaries were manually digitized and entered into a computer file. The quadrangle corner ticks were also digitized at the same time to provide map control points in State Plane Coordinates for reduction of the digitized positions to horizontal ground coordinates.



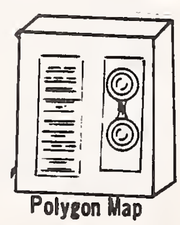


One of the most difficult tasks in the automation of the mapping process has been converting the graphical representations on maps or photos to numerical representations suitable for machine processing. Because the number of polygons or lines found on a typical forest map was quite large (over 1,500 individual forest units may occur within a single 7.5-minute quadrangle area) the task of manually digitizing a large forest area can be very time consuming. In an attempt to shortcut this often tedious and mistake-prone manual process, digitizing was accomplished using an electronic scanner. The scribe sheet prepared in the PI phase was electronically scan digitized using a Joyce Loebl Scandig Model 3 drum type microdensitometer (operating at the Pacific Southwest Forest and Range Experiment Station, Berkeley, California). This technique employs light sensitive recorders for determining the location of a line on a map document. Using this technique, large and very complex polygon maps can be digitized in a matter of minutes. The scanner generates a matrix of points (grid map) identifying the presence or absence of a line as a unique character within the matrix. Depending on the resolution of the scanner, the width of an individual line may be represented by one or more characters within the matrix.





The scanner matrix was processed using the Wildland Resource Information System (WRIS); recently renamed RID*POLY (Resource Information Display System - Polygon Processor). This system was developed by the Pacific Southwest Forest and Range Experiment Station (Russell, et al., 1975; Deschene, 1981; USDA Forest Service, 1982). Computer processing of the matrix involves four operations; (1) thinning the width of the digitized lines, (2) correcting missed or blurred lines, (3) extracting individual polygons, and (4) labeling each polygon. Reducing the line width to a single character prior to polygon extraction ensures that the line between polygons is identical. Editing for missing or run together lines requires a manual inspection of a printout of the scanner matrix. Although somewhat tedious, editing usually took less than 4 hours per 7.5-minute quadrangle area. Polygon extraction and labeling were performed together as a single process. The location and identity of the label are manually digitized on the original photograph and the polygon encompassing the label position is extracted from the grid map and



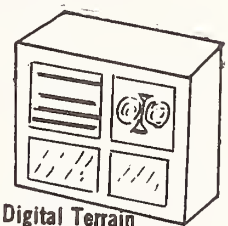
appropriately labeled. These digitized polygons are recorded in terms of the original photo document coordinate system and ready for further processing as described in the next section.

Another method for entering spatial data into a computer readable form is to enter actual ground survey information. Although a less common form of data entry, this method may be the most accurate. Field measurements of property lines, rights-of-way or road locations can be converted to standard ground coordinates and entered directly into computer files. By storing all spatial data in terms of a standard coordinate system, data from different sources, be it different scale maps, aerial photos or field surveys, can be incorporated into the same spatial data base.

Computer Processing of Geographic Information

Computer processing of geographic information involved three operations; (1) computing ground coordinates from measurements on aerial photographs, maps, or ground survey, (2) outputting the ground coordinates at different map scales and map or photo perspectives, and (3) calculating numerical measures such as areas, lengths, or accuracy statistics.

These processes have been integrated into a computer system called DTIS II (Digital Terrain Information System). DTIS II was developed and is currently maintained by the U.S. Forest Service Engineering Geometronics Development Group (Gossard, 1978; USDA Forest Service, 1981).



The principal advantage of DTIS II is the ability to store geographic information in a three-dimensional format. That is, all geographic features whether they are points, lines, or polygons are stored as strings of actual ground coordinates. DTIS II can convert features digitized from different source documents into a common coordinate system. By incorporating a digital terrain model, DTIS also computes an elevation for every digitized point, providing a three-dimensional representation for all stored geographic features.

Because aerial photographs are a principle source for forestry information, computing ground coordinates for photo-identified features is of primary importance. Using photogrammetric control, DTIS II computes transformation equations which along with digitial terrain data, are used to compute horizontal and vertical ground coordinates of features digitized from aerial photos. DTIS II can also perform the reverse. That is, when ground coordinates are known, coordinates on the photo perspective can be computed.

Combining the terrain model, map and photo transformation equations, and digitized geographic features, an integrated geographic data base is created. Graphical outputs can include contours, topographic cross sections or profiles, and polygons or lines at various map scales, photo perspectives or oblique perspectives. Numerical outputs include area or length computations, and statistics describing the accuracy of the transformation equations or terrain model. These statistics indicate the accuracy of both the original collection of photo or map points and the subsequent output.

MAPPING PROCESS

The techniques developed and used were designed primarily to provide an efficient and economic means for mapping Forest Land Units, but the process is quite flexible and readily adaptable to a wide range of mapping and resource analysis applications.

The USGS 7.5-minute topographic quadrangle was determined to be the most appropriate map base with final map products envisioned as overlays to this topographic base. The ownership, political and quadrangle boundaries were plotted on each quadrangle and manually digitized as closed polygons, edited to ensure polygon closure and continuity between common points and lines, and entered into a computer file.

For each 7.5-minute quadrangle area a DMA digital terrain model was acquired from USGS. To facilitate the efficient collection of information, small scale high resolution photography was selected. Quad-centered 1:80,000 scale panchromatic film transparencies were purchased from the USGS. Photogrammetric control prepared by the USGS was also purchased. The photogrammetric control and terrain model along with the digitized ownership, political and quadrangle boundaries were entered into DTIS II.

The quadrangle and ownership boundaries were processed using DTIS II and drawn by a computer controlled plotter in the perspective of the 1:80,000 scale aerial photographs used for the photointerpretation. This plot, or photo collar, was traced onto the aerial photograph providing a means for identifying ownership patterns and facilitating edge-matching between adjacent quadrangles. The photo collar also provided information about the ownership and political jurisdiction of each mapped Forest Land Unit that was later included in an attribute file describing each mapped quadrangle area.

Upon completing the photointerpretation, the FLU boundaries were manually redrafted onto the original photo collar. The collar and FLU boundaries were electronically scan digitized and computer processed to produce a file of closed polygons representing each delineated Forest Land Unit. Processing of the scanner data was accomplished using the Forest Service computer system RID*POLY.

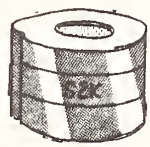
In order to transform the digitized Forest Land Unit polygon coordinates from the x,y photo coordinate system to X, Y, and Z ground coordinates, the polygon records were processed through DTIS II. Again using the computed transformation equations for each photograph and the terrain model; X, Y, and Z ground coordinates were calculated for each digitized x,y photo coordinates, as well as for each slope change or inflection point between digitized points as indicated by the terrain model. Ground coordinates for Forest Land Unit boundaries were stored in the DTIS II data base along with the ownership, political and quadrangle boundaries. DTIS II also computed the acreage, the polygon perimeter length, the maximum and minimum ground coordinates and coordinates of the label location associated with each polygon. This information provided quantitative spatial information about each Forest Land Unit and a simple tabular index for locating each unit.

Forest Land Unit Map File

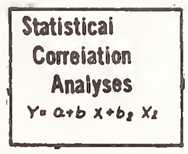
Additional details on the mapping process and information on photo-to-map transfer accuracy using different terrain models can be found in Martin (1983).

DATA STORAGE

Although DTIS II does an admirable job of managing and integrating geographic information, only limited storage and retrieval capability exists for attribute data associated with the stored geographic features. To provide a more comprehensive query and analysis capability the geographic files of DTIS II were linked with an attribute management information system. The management information system used was a general purpose data base management system called System 2000 (S2K) developed and marketed by MRI Systems Corporation, Austin, Texas. The internal DTIS II identifier for each FLU, along with the acreage, length, maximum and minimum ground coordinates and label location for each unit were output and read into the data base management system. The photointerpreted topographic and forest overstory characteristics coded during photointerpretation of the FLU's as well as available ground information for each FLU were also input to S2K. In this way a relatively small tabular file was created representing all of the thousands of individually delineated forest units.



IV. GROUND SAMPLE EXPANSION



The objective of this phase was to evaluate the usefulness of the photointerpreted FLU characteristics for expanding an extensive ground sample. To make this evaluation, a statistical analyses was performed to determine the ability to predict ground attributes (dependent variables) from the PI characteristics (independent variables).

The Montana forest survey plots established on State and private lands in and around Missoula County were used to provide ground attributes. These plots were measured in 1978 and represent the most up-to-date information available.

The dependent variables were measured on two different scales. Volume, growth, site index, yield capability, and stocking were considered as continuous scale variables, while forest type, stand size class, and habitat type were considered as nominal (categorical) scale variables. The continuous scale dependent variables were analyzed using multiple linear regression while the nominal scale dependent variables were analyzed using discriminant analysis. The data were analyzed using computer routines from SPSS (Statistical Package for the Social Sciences, Nie et al., 1975).

The following 14 ground attributes (dependent variables) were selected for testing:

1. Scribner (Accumulated volume/acre)
2. International (Accumulated volume/acre)
3. Cubic Foot (Accumulated volume/acre)
4. Scribner (Annual growth/acre)
5. International (Annual growth/acre)
6. Cubic Foot (Annual growth/acre)
7. Yield Capability
8. Site Index
9. Stocking
10. Crown Competition Factor
11. Basal Area
12. Stand Size
13. Forest Type
14. Habitat Type

The source of independent variables was the FLU characterizations determined by the photointerpretation. In Table 1, the worthiness of these variables as predictors is suggested by the frequency of categories encountered on the 296 ground sampled Forest Land Units.

Regression Analysis

The regression equations developed for each of the 11 continuous scale dependent variables have the linear form:

$$(Y' = a + b_1X_1 + b_2X_2 \ldots + b_nX_n)$$

The constant "a" and the coefficients, b_1, b_2, etc., are computed through a recursive least squares procedure. For each dependent variable, the predicted value, Y' is calculated. Table 2 lists PI characteristics included in the multiple linear regression analysis performed on the 11 continuous scale dependent variables.

TABLE 1 DISTRIBUTION OF INDEPENDENT VARIABLES

PHOTOGRAPHIC PATTERN	CODE	PLOT FREQUENCY
UNIFORM	1.	69
MOTTLED	2.	50
PARTIALLY BROKEN	3.	63
VERY BROKEN	4.	114
	TOTAL	296

PHOTOGRAPHIC TEXTURE	CODE	PLOT FREQUENCY
COARSE	1.	4
MEDIUM COARSE	2.	71
MEDIUM FINE	3.	160
FINE	4.	61
	TOTAL	296

CROWN CANOPY COVERAGE	CODE	PLOT FREQUENCY
ABOVE 80 PERCENT	1.	96
70 TO 80 PERCENT	2.	43
50 TO 69 PERCENT	3.	67
25 TO 49 PERCENT	4.	58
UNDER 25 PERCENT	5.	32
	TOTAL	296

AVERAGE STAND HEIGHT	CODE	PLOT FREQUENCY
ABOVE 120 FEET	1.	3
90 TO 120 FEET	2.	24
60 TO 89 FEET	3.	162
30 TO 59 FEET	4.	88
UNDER 30 FEET	5.	19
	TOTAL	296

AVERAGE CROWN SIZE	CODE	PLOT FREQUENCY
ABOVE 40 FEET	1.	3
25 TO 40 FEET	2.	40
15 TO 24 FEET	3.	148
6 TO 15 FEET	4.	78
UNDER 6 FEET	5.	27
	TOTAL	296

LAND OR VEGETATION MODIFIER	CODE	PLOT FREQUENCY
NONE	1.	202
LOGGED	2.	89
ROCKY SURFACE	6.	2
SWAMPY OR WET BOTTOM	8.	1
TWO-STORIED STAND	9.	2
		296

TOPOGRAPHIC EXPOSURE	CODE	PLOT FREQUENCY
FLAT	1.	35
N	2.	39
NE	3.	30
E	4.	35
SE	5.	33
S	6.	35
SW	7.	30
W	8.	35
NW	9.	24
	TOTAL	296

SLOPE ANGLE	CODE	PLOT FREQUENCY
0 TO 5 PERCENT	1.	38
6 TO 15 PERCENT	2.	27
16 TO 25 PERCENT	3.	41
26 TO 35 PERCENT	4.	47
36 TO 45 PERCENT	5.	67
46 TO 65 PERCENT	6.	64
66 TO 85 PERCENT	7.	11
ABOVE 85 PERCENT	8.	1
	TOTAL	296

TOPOGRAPHIC POSITION	CODE	PLOT FREQUENCY
TALWEG	1.	26
MIDSLOPE DRAIN	2.	7
MIDSLOPES	3.	262
MIDSLOPE RIDGE	4.	1
	TOTAL	296

CONTOUR CURVATURE	CODE	PLOT FREQUENCY
CONCAVE	1.	6
UNDULATING	2.	8
STRAIGHT	3.	279
CONVEX	4.	3
	TOTAL	296

ELEVATION	CODE	PLOT FREQUENCY
2501 TO 3000 FEET	3.	2
3001 TO 3500 FEET	4.	15
3501 TO 4000 FEET	5.	47
4001 TO 4500 FEET	6.	77
4501 TO 5000 FEET	7.	73
5001 TO 5500 FEET	8.	41
5501 TO 6000 FEET	9.	26
6001 TO 6500 FEET	10.	14
6501 TO 7000 FEET	11.	1
	TOTAL	296

AVERAGE PRECIPITATION	CODE	PLOT FREQUENCY
10 TO 19 INCHES	1.	76
20 TO 29 INCHES	2.	130
30 TO 39 INCHES	3.	65
40 TO 49 INCHES	4.	16
50 TO 59 INCHES	5.	5
60 TO 69 INCHES	6.	4
	TOTAL	296

COUNTY LOCATION	CODE	PLOT FREQUENCY
GRANITE	2.	2
MINERAL	4.	28
MISSOULA	5.	251
POWELL	6.	13
RAVALLI	7.	1
SANDERS	8.	1
	TOTAL	296

FOREST TYPE	CODE	PLOT FREQUENCY
PONDEROSA PINE	1.	64
DOUGLAS FIR	2.	105
MIXED UPLAND CONIFER	3.	58
MIXED BOTTOM CONIFER	4.	9
LODGEPOLE PINE	5.	38
MIXED HARDWOODS	6.	4
UNDETERMINED	8.	18
	TOTAL	296

TABLE 2 PHOTOINTERPRETED AND CULTURAL VARIABLES DETERMINED TO BE RELEVANT IN PREDICTING GROUND ATTRIBUTES

	DEPENDENT VARIABLES FROM GROUND TRUTH PLOTS	INDEPENDENT VARIABLES FROM THE PHOTO INTERPRETATION PHASE OF STUDY															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		PATTERN	TEXTURE	CROWN COVER	STAND HEIGHT	CROWN SIZE	MODI- FIER	ASPECT	SLOPE ANGLE	POSI- TION	CONTOUR CURVA- TURE	ELEVA- TION	PRECIP- ITATION	COUNTY	OWNER- SHIP	RIVER BASIN	FOREST TYPE
1	VOLUME - SCRIBNER		X	X	X	X											
2	VOLUME - INTERNATIONAL		X	X	X	X											
3	VOLUME - CUBIC FOOT		X	X	X	X				X			X				X
4	GROWTH - SCRIBNER			X		X		X	X								X
5	GROWTH - INTERNATIONAL			X		X		X	X								X
6	GROWTH - CUBIC FOOT			X				X				X					X
7	YIELD CAPABILITY		X	X	X	X			X			X					X
8	SITE INDEX			X	X	X						X					X
9	STOCKING			X		X			X			X					
10	CROWN COMPETITION FACTOR			X			X						X				
11	BASAL AREA		X	X			X						X				

Regression results are summarized in Table 3, where it is evident that the volume predictions are superior to the other dependent variables tested. The "F" test on all the regressions in Table 3 is significant at 0.01 probability, meaning that for all 11 dependent variables, there is less than a 1 percent chance that the relationship between the dependent variable and at least one independent variable could have occurred due to random variation. In other words, it implies that there is a linear relationship between one or more of the independent variables and the dependent variable. The "F" value by itself does not tell whether one or all of the independent variables contribute. The correlation coefficient squared (R^2) gives an indication of the amount of total variation in the original dependent variable that has been removed or is explained by the regression equation. The power of regression over the simple mean can be appreciated by comparing the absolute sizes of the standard error with the standard deviation.

ESTIMATED GROUND ATTRIBUTE DATA BASE

The equations for standing volume are ready for verification trials as a subsequent step in the scientific development of this new technology. The volume for each FLU predicted by the regression equations shown in Table 4 have been added to the FLU files in the System 2000 data base and volumes have been predicted and stored for all the FLU's on several 7.5-minute quadrangles. The scatter plots of predicted versus observed values for standing volume are shown in Figures 4, 5, and 6.

The remaining eight dependent variables listed in Table 3, though not as predictable as volume, could be improved through additional analysis. Attempts were made to stratify some of these continuous dependent variables into two groups and test how well strata membership could be identified using the independent (PI) variables in discriminate analysis equations. The following categories were defined and tested.

Original Dependent Variable	Grouping Criteria	Definition of New Group	Actual No. of Cases
Yield Capability	$\geq$ 85 cubic feet	Prime forest land	73
Yield Capability	< 85 cubic feet	Non-prime forest land	223
			296

The resulting discrimination function classified 84 percent of the cases correctly as prime or non-prime forest land.

Original Dependent Variable	Grouping Criteria	Definition of New Group	Actual No. of Useable Cases
CCF	$\geq$ 200	Overstocking	32
CCF	< 200	Other stocking	215
			247 1/

1/ Not all of the 296 ground samples had CCF values calculated for them.

TABLE 3

Summary of Regression Analysis Results
in Terms of Goodness of Fit and
Significance of Equations

	Without Regression		With Regression		
	Simple Mean	Standard Deviation	Correl. Coef. Squared (R^2)	Standard Error	No. of Variables
Volume					
Scribner	4663	4135	.94	986	7
International	5621	4841	.94	1170	7
Cubic Foot	1596	1187	.74	609	6
Growth					
Scribner	124	119	.33	98	5
International	142	140	.29	118	5
Cubic Foot	41	42	.21	37	5
Yield Capability	71	24	.38	19	6
Site Index	56	13	.28	11	4
Stocking	82	34	.36	27	4
Crown Competition Factor	133	68	.32	56	3
Basal Area	86	51	.54	34	4

TABLE 4 - VOLUME EQUATIONS

Scribner Volume $= 75541.04 - 502.4576\ X_1 - 13770.5\ X_2 - 431.2544\ x_3$

$- 8.301792\ X_4 + 141.6536\ X_5 + 37.63556\ X_6$

$+ 0.001530422\ (X_3 \cdot X_4 \cdot X_7)$

International Volume $= 78921.8 - 637.8273\ X_1 - 14378.7\ X_2 - 447.4798\ X_3$

$- 10.02352\ X_4 + 181.7246\ X_5 + 47.20453\ X_6$

$+ 0.001765286\ (X_3 \cdot X_4 \cdot X_7)$

Cubic Foot Volume $= 632.0029 + 0.2430285\ X_8 + 0.1122064\ X_9 - 201.7638\ X_{10}$

$+ 439.7371\ X_{11} - 92.83039\ X_{12}$

$+ 0.000001342386\ (X_3 \cdot X_4 \cdot X_6 \cdot X_7)$

where volume is in board feet or cubic feet per acre and where

X_1 = crown canopy cover code

X_2 = average stand height in code

X_3 = average stand height in feet

X_4 = crown size in feet squared

X_5 = crown size in feet

X_6 = texture index

X_7 = crown canopy cover percent

X_8 = crown canopy cover percent squared

X_9 = average stand height in feet squared

X_{10} = topographic position code

X_{11} = natural log of precipitation in inches

X_{12} = forest type ranked by volume

FIGURE 4 PREDICTED VS. OBSERVED SCRIBNER BOARD FOOT VOLUME

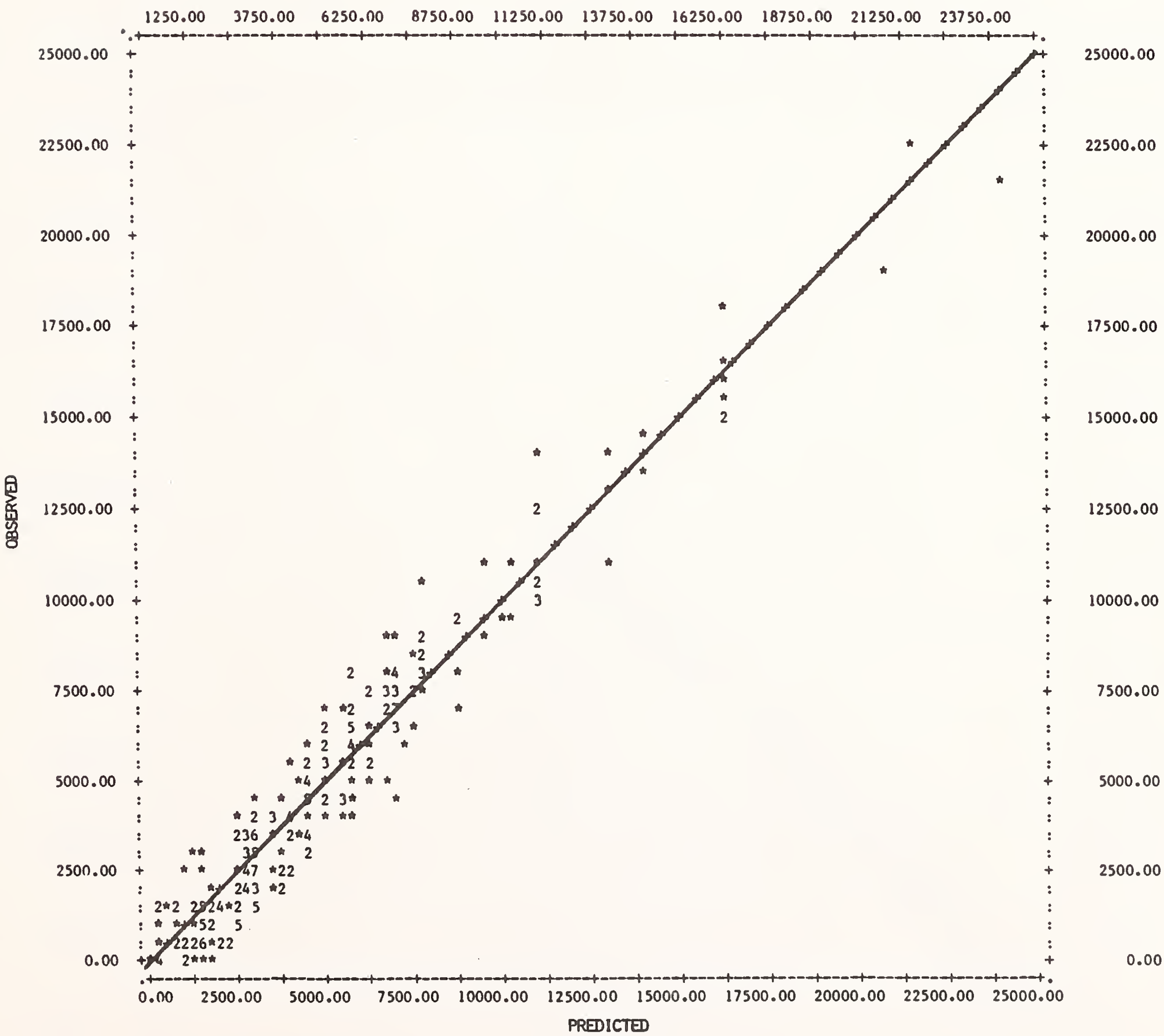


FIGURE 5 PREDICTED VS. OBSERVED INTERNATIONAL BOARD FOOT VOLUME

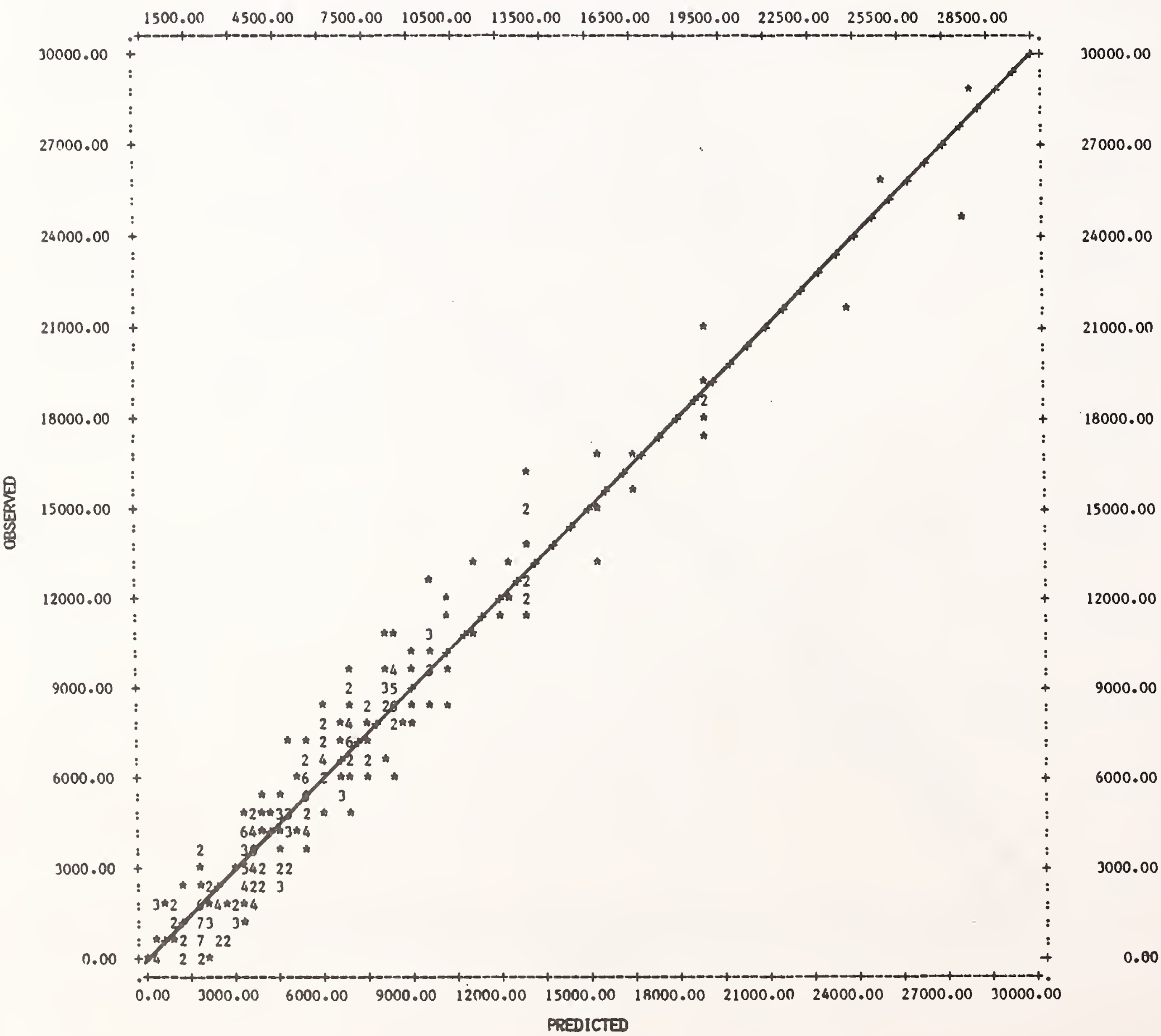
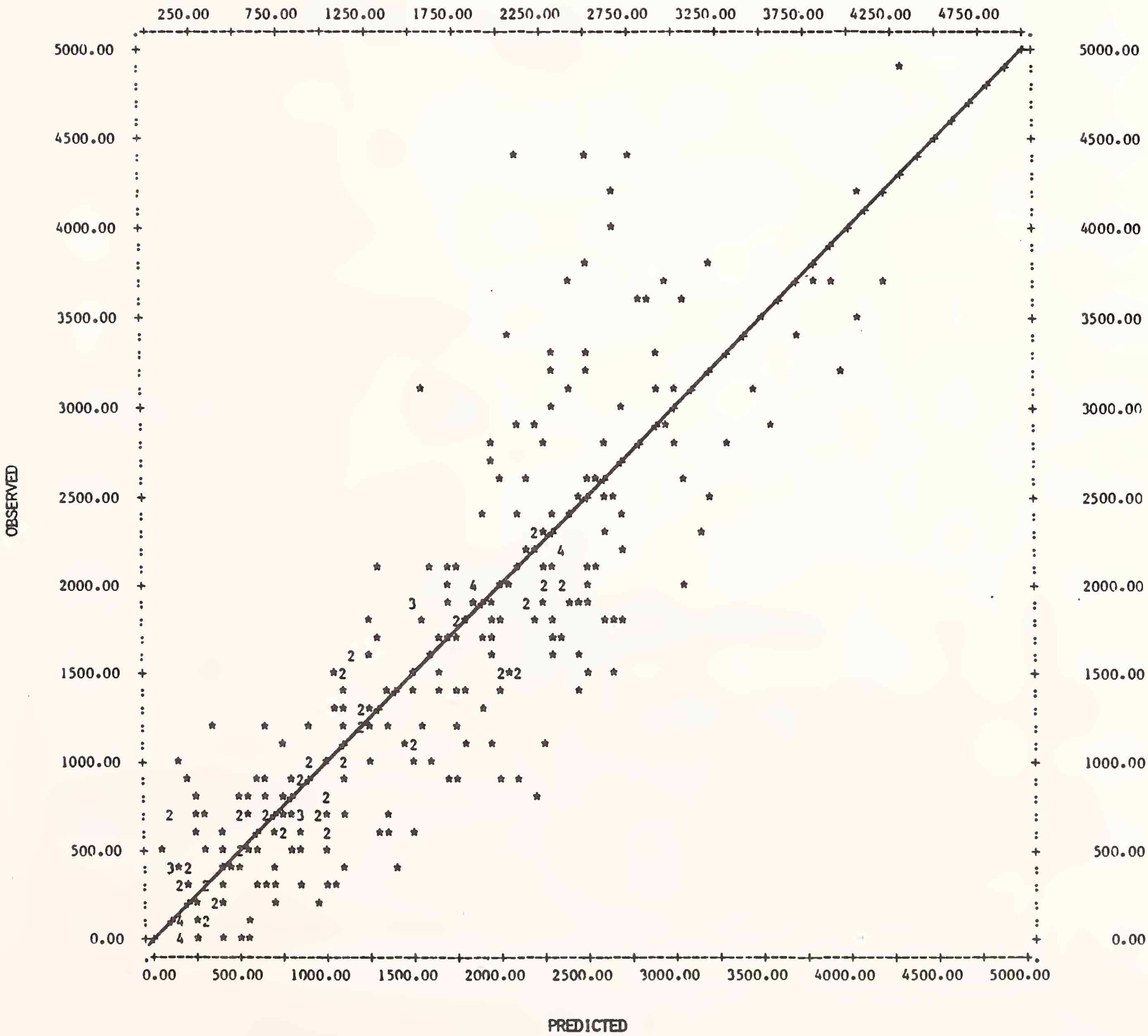


FIGURE 6 PREDICTED VS. OBSERVED CUBIC FOOT VOLUME



The use of a Crown Competition Factor (CCF) of 200 and greater as a definition for overstocking is not official but is presented merely to show how a prediction of stocking could be set up. The resulting discrimination function correctly classified 74 percent of the cases into overstocked and understocked categories. There may be natural clusterings along continuous scale measurements which would call for a different grouping criteria and which, if used to develop discrimination functions, could improve the percentage of correct classifications.

Discriminate Analysis

The remaining three ground truth attributes tested were stand size class, forest type and habitat. Because these attributes constitute definable categories, discriminate analysis is more appropriate than regression analysis for studying their relationship with the independent variables. This technique produced a separate prediction equation (similar in form to a linear regression equation) for each category of the dependent variable. By solving each of the equations for each case, a set of discriminant scores is generated. These scores are then converted into probabilities for predicting the dependent variable category for each case. Comparison of the predicted category frequency with the actual frequency gives the percentage of correctly classified categories for each dependent variable.

Table 5 shows the discriminate analysis classification results.

TABLE 5
DISCRIMINANT ANALYSIS CLASSIFICATION RESULTS

Dependent Variable and (No. of Categories)	Percent Correctly Classified MPG*	1st & 2nd MPG*
Stand Size Class (5 classes)	62	87
Forest Type (6 types)	72	89
Habitat:		
Type & Phase (61 types & phases)	41	58
Groups used for Lolo NF Plan (10 groups)	38	66
Series (10 series)	44	81

* MPG is the Most Probable Group

Some improvement in discrimination was achieved by regrouping the stand size classes into simpler two-level classifications. The following categories were defined and tested:

Original Dependent Variable	MFS Group Codes	Definition of New Group	Actual No. of Useable Cases
1st Discrimination			
Stand Size Class	Codes 1 & 2	Sawtimber	174
Stand Size Class	Codes 3, 4 & 5	Non-sawtimber	120
			294 1/
2nd Discrimination			
Stand Size Class	Codes 1, 2, 3, & 4	Stocked	289
Stand Size Class	Code 5	Nonstocked	5
			294 1/

The developed discrimination functions correctly classified 85 percent of the cases into sawtimber and non-sawtimber and 89 percent of the cases into stocked and nonstocked.

The original 10 forest types identified in the MFS ground sample were reduced to six forest types as follows:

Definition of New Group	Actual No. of Useable Cases
Ponderosa pine	57
Douglas-fir	135
Spruce-Alpine fir-Larch	40
Spruce-Red Cedar	12
Lodgepole pine	46
Cottonwood	3
	293

This grouping produced better discrimination results than did the original 10 groups--72 percent as opposed to 68 percent of the cases correctly classified. The independent variables used in the discrimination function are; (1) pattern, (2) elevation, (3) slope, (4) aspect, (5) the interaction product of texture times percent crown cover times crown diameter squared; and (6) the photointerpreters direct estimate of forest type. The last of these independent variables, the direct photointerpretation of forest type, is sufficient enough to be used as a single predictor variable in a simple cross tabulation against the ground truth forest type. Using this variable alone in a cross tabulation produced a 75 percent correct classification overall as shown in Table 6. 2/ Summing the cases along the diagonal and dividing by 275 provides the proportion of correctly classified cases.

Habitat type had the poorest classification results.

1/ Not all of the 296 ground plots had stand size and stocking values recorded.

2/ Not all of the 296 ground plots had forest types identified. Of the 293 forest types identified, the photointerpreter coded 18 of them as undeterminable because of no tree cover or because of immature stand development.

TABLE 6
CROSS TABULATION OF PHOTOINTERPRETED FOREST TYPE
COMPARED WITH GROUND TRUTH FOREST TYPE

Actual as verified by ground plots	Predicted by direct photo interpretation						
	Ponderosa Pine 1	Doug-fir 2	Mixed Upland Conifer 3	Mixed Bottom Conifer 4	Lodge-pole Pine 5	Mixed Hard-woods 6	TOTAL
	(------------------- Number of Cases					------------------)	
Pondersona pine 1	45	7	2	0	0	2	56
Douglas-fir 2	15	93	16	1	5	0	130
Spruce-Alpine fir - Larch 3	3	1	27	1	1	0	33
Englemann Spruce Red Cedar 4	0	0	4	7	0	0	11
Lodgepole Pine 5	0	3	7	0	32	0	42
Cottonwood 6	0	0	1	0	0	2	3
Column Total	63	104	57	9	38	4	275
Percent Correct Classification	71.4%	89.4%	47.4%	77.8%	84.2%	50.0%	75.0%

V. PRODUCTS OF THE SYSTEM

PRODUCTS OF THE SYSTEM

Once the Forest Land Unit (FLU) boundaries were entered into DTIS II it was possible to generate a number of different output documents. Maps were output at a variety of scales simply by specifying a desired scale factor. "Windowing" capability permitted output for selected rectangular areas. Contours were generated from the digital terrain model and by plotting the contours along with the quadrangle, ownership, and FLU boundaries, a composite topographic map was drawn entirely via computer controlled plotter. Also, provided the transformation equations for other aerial photographs are computed and stored within DTIS II, Forest Land Units and other stored features can be plotted in the perspective of an aerial photograph. Such a plot would precisely fit the air photo, including proper compensation for topographic relief displacements. Data for each FLU or combinations of selected FLU's can also be summarized and tabulated from the S2K computer data base.

Examples of these output products are shown in Figures 7 through 15. Figure 7 is a computer drawn FLU map originally drawn at 1:24,000 scale as an overlay to a 7.5-minute topographic base map. The interpreted map in Figure 8 was produced in two steps. First the FLU's having the desired characteristic, such as a particular volume (in this case $\geq$ 7,000 BFS volume per acre) and forest type (in this case Douglas-fir and mixed conifer) were selected from the S2K data base. Second, the chosen FLU's were entered into DTIS II and selectively drawn as an overlay to a 7.5-minute topographic base map. The cross-hatching of forest types was added photographically during reproduction using computer generated "peel-coat" overlays. The legend was added manually to assist in the interpretation of the figure. Figure 9 is a partial display of a computer generated table summarizing some of the data associated with the interpreted map in Figure 8.

In addition to mapping FLU's from high altitude aerial photographs, a test was conducted on the capability of updating existing road maps by digitizing road locations on large scale photography. Recently flown normal color 1:12,000 scale photography was secured for a contiguous ten (10) square mile area. A DTIS II data base for the area was created that included a high resolution digital elevation model (DEM) developed by the USGS, photogrammetric control, and digitized section corners. Because the road network was not excessively dense, we chose to manually digitize the roads directly from the photographs, rather than to redraft them onto a medium suitable for electronic scanning. Since some of the roads had already been mapped on the USGS 7.5-minute topographic map, and had been previously digitized along with the section lines, only the new unmapped roads were digitized from the color photos. Photo transformation equations computed within DTIS II were used to calculate the ground coordinates for each digitized road segment. DTIS II computed additional horizontal and vertical ground coordinates between input digitized points whenever a change in the slope of the ground as portrayed by the terrain model was encountered. Portions of the same road digitized from different photographs were linked together within DTIS II to form a continuous road alignment.

FLU's previously scan digitized from the 1:80,000 scale high altitude photos, along with stream locations and two proposed road locations digitized from the 7.5-minute topographic map, were also entered into the DTIS II system

files for the 10-section project area, thus creating a multi-facet, multi-source geographic data base. Outputs from this data base included contours, FLU's, roads, and streams plotted at various map scales on overlays for 1:12,000 scale color air photos and on perspective plots. Figure 10 demonstrates the photo composite construction.

The existing roads digitized from both the 7.5-minute quadrangle and the 1:12,000 scale photos are shown in Figures 11 and 12. Misregistration of roads in the upper left corner of Figure 11 is the result of errors in the original 7.5-minute topographic quadrangle map as determined by comparing the original map and an orthophoto map. The dashed lines in Figure 11 show proposed road locations. Figure 12 is a composite plot of contours, roads, streams, section lines, and FLU's. Roads digitized from the 7.5-minute quadrangle are shown as solid lines, while roads digitized from the air photos are shown dashed. Figure 13 is a cross sectional profile along line 3029 shown on Figure 12. Figure 14 is an oblique perspective plot of the same area as Figure 12. Figure 15 is an example of a computer printout listing photointerpreted, predicted ground attributes and acreage by FLU number stored in the S2K data base.

One of the original Timber-Water Study objectives was to produce an interpretative map showing those lands capable of growing 85 or more cubic feet of wood per acre per year--the Department of Agriculture volume growth rate per acre criteria for prime forest land. Considerable work is being done and examples of prime forest land maps are being circulated from other parts of the country. Prime forest land interpretations can also be a product of the system presented in this report, but unfortunately the statistical results in Table 3 are not favorable enough without further analysis to make a satisfactory interpretation of prime land at this time. This is further substantiated by the discrimination analysis discussed in the previous chapter wherein 84 percent of the sample cases were correctly classified into prime and nonprime categories. The resulting functions also classified 14 percent of the nonprime lands (assuming the ground truth is correct) to be prime forest land and classified 23 percent of the prime lands (assuming the ground truth is correct) to be nonprime. Should one have use for yield and prime land information even with these accuracy limitations, the system can generate copious interpreted maps and acreage statistics. However, examples of prime land interpretative maps are not included in this report to avoid any misunderstanding that they be deemed suitable for general use.

A summary of the following products and some potential uses are listed as follows:

Figure No.	Product	Use
7	Forest Land Unit Map	--Preliminary forest land appraisal --Inventory of forest characteristics --Basic stand map
8	Interpreted Map	--Identification of similar areas to evaluate management options --Resource planning and development

Figure No.	Product	Use
9	Tabular Report of Interpreted Map Data	--Quantification and evaluation of mapped interpreted resource information
11	Photo Composite	--Preliminary timber sale layout and project level reconnaissance --Trespass identification and prevention --Road location update
12	Topographic Composite	--Preliminary timber sale layout and road location and design --Vegetative and geographic overlays with other resource information for forest management planning
13	Cross Sectional Profile	--Road, logging system, and transmission line design
14	Oblique Perspective	--Visual quality evaluation
15	System 2000 Output Listing	--Quantification of mapped information and evaluation of data for resource management options and project development

FIGURE 7 FOREST LAND UNIT OVERLAY TO A 7.5-MINUTE TOPOGRAPHIC QUAD

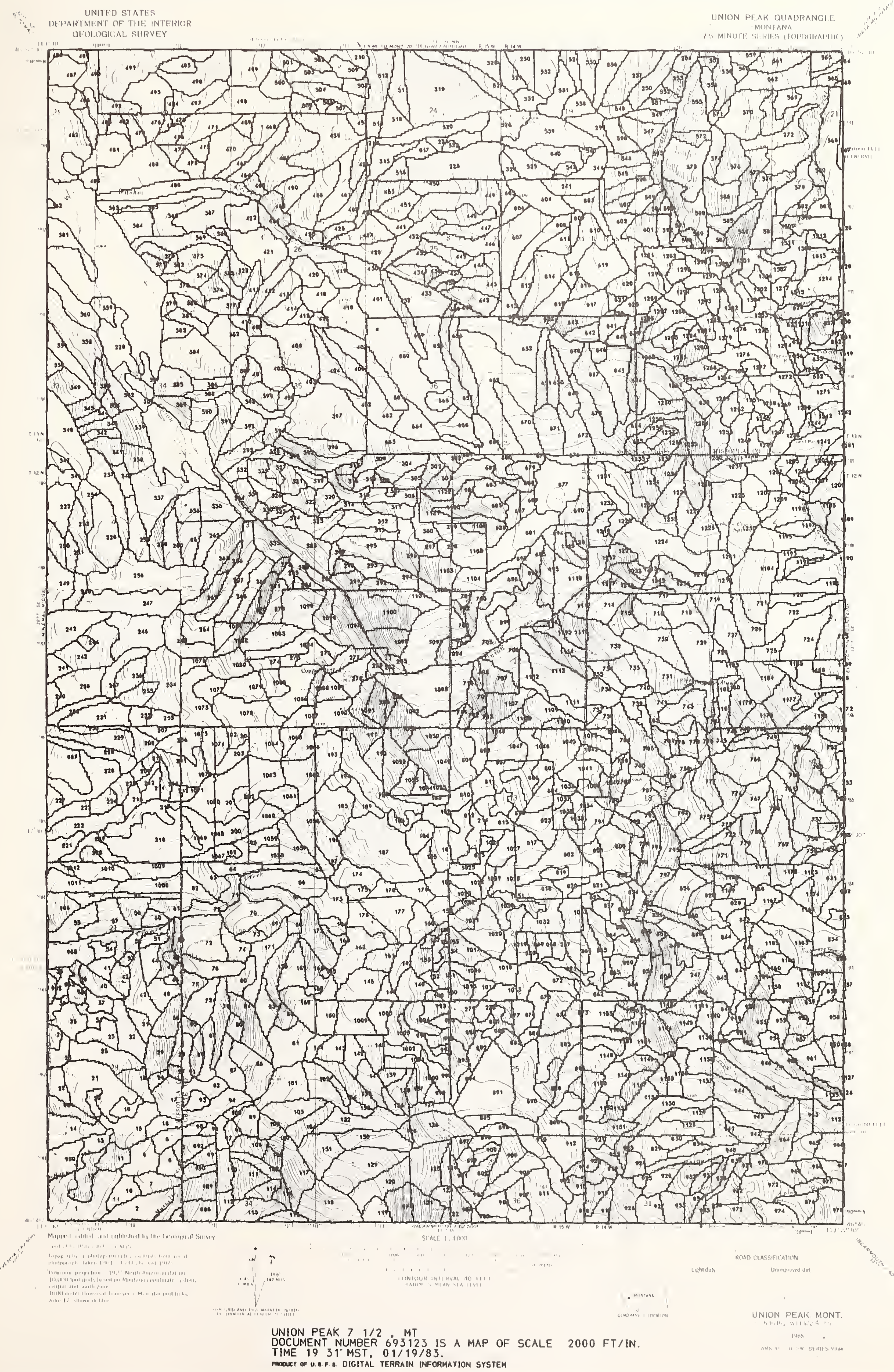


FIGURE 8 INTERPRETED MAP

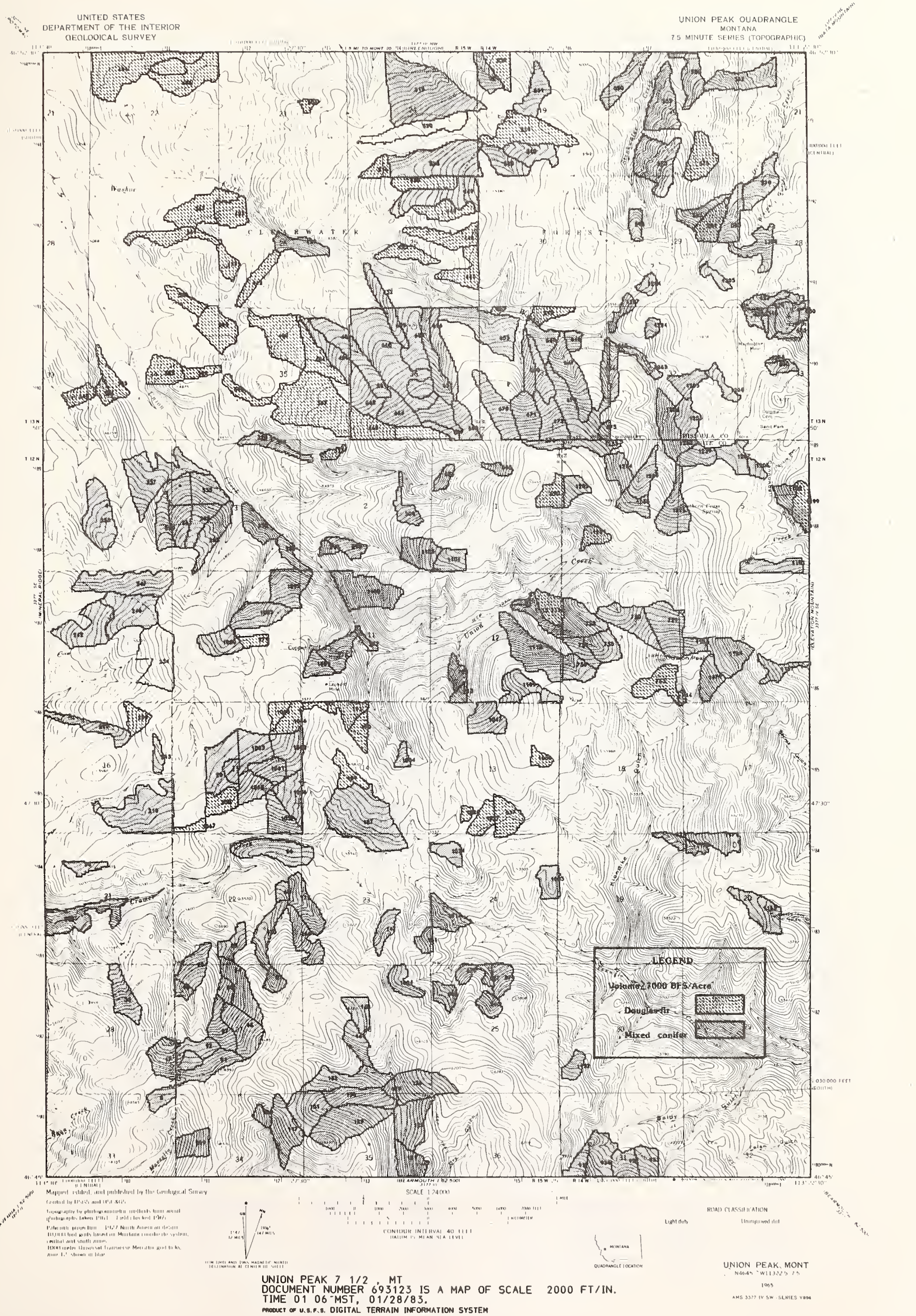


FIGURE 9 TABULAR REPORT EXAMPLE OF INTERPRETED MAP DATA
Union Peak Quad

FLUS WITH 7000 BFS VOLUME PER ACRE OR MORE
01/12/1983

*	FLU #	BFS PER ACRE	ACREAGE	FOREST TYPE	SLOPE ANGLE	ASPECT	OWNERSHIP	TOPOGRAPHIC POSITION
***								
*	8	7850	18	MXUPCONF	26-35%	S	PRIVATE	MIDSLOPE
*	17	10335	35	MXUPCONF	26-35%	N	PRIVATE	M DRAIN
*	32	8631	39	MXUPCONF	26-35%	N	PRIVATE	MIDSLOPE
*	56	10952	15	MXUPCONF	26-35%	N	PRIVATE	MIDSLOPE
*	66	13101	57	MXUPCONF	26-35%	N	PRIVATE	MIDSLOPE
*	68	7850	9	MXUPCONF	26-35%	NE	PRIVATE	MIDSLOPE
*	78	13101	35	MXUPCONF	26-35%	NW	PRIVATE	MIDSLOPE
*	80	7850	23	MXUPCONF	36-45%	W	PRIVATE	MIDSLOPE
*	82	7850	14	MXUPCONF	36-45%	N	PRIVATE	M DRAIN
*	84	7850	46	MXUPCONF	36-45%	W	PRIVATE	MIDSLOPE
*	85	8631	13	MXUPCONF	36-45%	W	PRIVATE	MIDSLOPE
*	86	7850	50	MXUPCONF	36-45%	NW	PRIVATE	MIDSLOPE
*	87	16149	32	MXUPCONF	36-45%	NW	PRIVATE	MIDSLOPE
*	90	7850	9	MXUPCONF	36-45%	NW	PRIVATE	MIDSLOPE
*	92	10952	25	MXUPCONF	26-35%	N	PRIVATE	MIDSLOPE
*	94	10952	40	MXUPCONF	26-35%	N	PRIVATE	MIDSLOPE
*	108	8631	10	MXUPCONF	36-45%	E	PRIVATE	MIDSLOPE
*	117	10952	50	MXUPCONF	36-45%	W	PRIVATE	MIDSLOPE
*	121	10335	30	MXUPCONF	46-65%	W	PRIVATE	MIDSLOPE
*	125	16149	53	MXUPCONF	36-45%	W	PRIVATE	MIDSLOPE
*	126	10952	57	MXUPCONF	36-45%	SW	PRIVATE	MIDSLOPE
*	128	7599	7	MXUPCONF	36-45%	E	PRIVATE	MIDSLOPE
*	129	10335	81	MXUPCONF	26-35%	NE	PRIVATE	MIDSLOPE
*	130	7850	45	MXUPCONF	26-35%	SE	PRIVATE	MIDSLOPE
*	131	7850	47	MXUPCONF	26-35%	E	PRIVATE	MIDSLOPE
*	132	7850	55	MXUPCONF	26-35%	NE	PRIVATE	MIDSLOPE
*	140	10952	25	MXUPCONF	26-35%	E	PRIVATE	MIDSLOPE
*	141	10952	25	MXUPCONF	26-35%	SW	PRIVATE	MIDSLOPE
*	147	10335	22	MXUPCONF	36-45%	NW	PRIVATE	MIDSLOPE
*	151	10952	13	MXUPCONF	36-45%	E	PRIVATE	MIDSLOPE
*	166	10952	36	MXUPCONF	36-45%	NW	PRIVATE	MIDSLOPE
*	170	7850	35	MXUPCONF	26-35%	E	PRIVATE	MIDSLOPE
*	172	8631	43	MXUPCONF	36-45%	NW	PRIVATE	MIDSLOPE
*	187	8631	131	MXUPCONF	16-25%	SW	PRIVATE	MIDSLOPE
*	189	7690	23	DOUG-FIR	26-35%	SW	PRIVATE	MIDSLOPE
*	190	7850	19	DOUG-FIR	26-35%	NE	PRIVATE	MIDSLOPE
*	191	10335	24	DOUG-FIR	36-45%	E	PRIVATE	MIDSLOPE
*	192	10952	6	DOUG-FIR	16-25%	NW	PRIVATE	MIDSLOPE
*	200	10952	26	DOUG-FIR	26-35%	NW	PRIVATE	MIDSLOPE
*	201	8631	51	MXUPCONF	16-25%	NW	PRIVATE	MIDSLOPE
*	208	7850	20	DOUG-FIR	26-35%	W	STATE	MIDSLOPE
*	213	8631	12	MXUPCONF	16-25%	SW	STATE	MIDSLOPE
*	1262	16149	18	MXBTCONF	26-35%	N	BLM	M DRAIN
*	1263	16149	16	MXBTCONF	6-15%	NW	BLM	M DRAIN
*	1265	16149	22	MXUPCONF	26-35%	N	BLM	MIDSLOPE
*	1268	7850	16	MXUPCONF	16-25%	NW	BLM	MIDSLOPE
*	1273	7850	3	MXUPCONF	26-35%	NW	BLM	MIDSLOPE
*	1284	10011	9	MXUPCONF	16-25%	S	BLM	MIDSLOPE
*	1287	7850	14	MXUPCONF	36-45%	W	BLM	MIDSLOPE
*	1294	10052	12	MXUPCONF	16-25%	NW	BLM	MIDSLOPE
*	1305	13101	12	MXUPCONF	16-25%	NW	BLM	M RIDGE
*	1308	10952	35	MXUPCONF	36-45%	N	BLM	MIDSLOPE
*	1318	7850	5	MXUPCONF	26-35%	N	BLM	MIDSLOPE

SUMMARY

Forest Type	Total Acres	Average Acres/FLU	Total # FLU's	Total Volume	Average Vol./FLU	Average Vol./Acre
Douglas Fir	1,575	29.7	53	15,060,186	284,154	9,562
Mixed Conifer	5,991	32.7	183	62,225,648	340,030	10,386
Other	120	60.0	2	1,361,739	680,870	11,347
Total	7,680	32.29	238	78,647,573	330,452	10,232

FIGURE 10 **PHOTO COMPOSITE CONSTRUCTION**

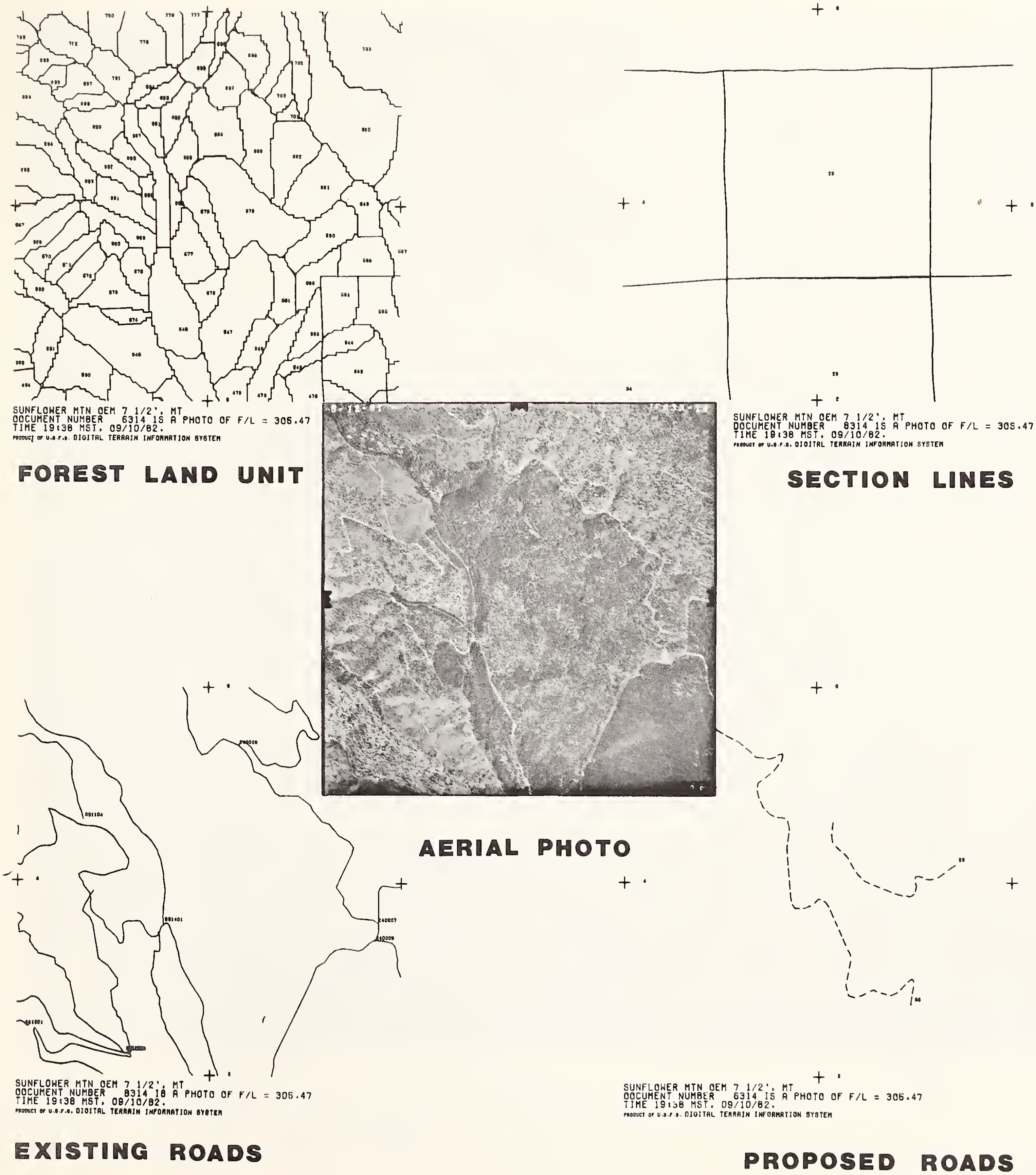
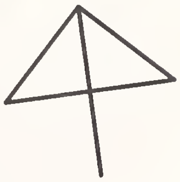


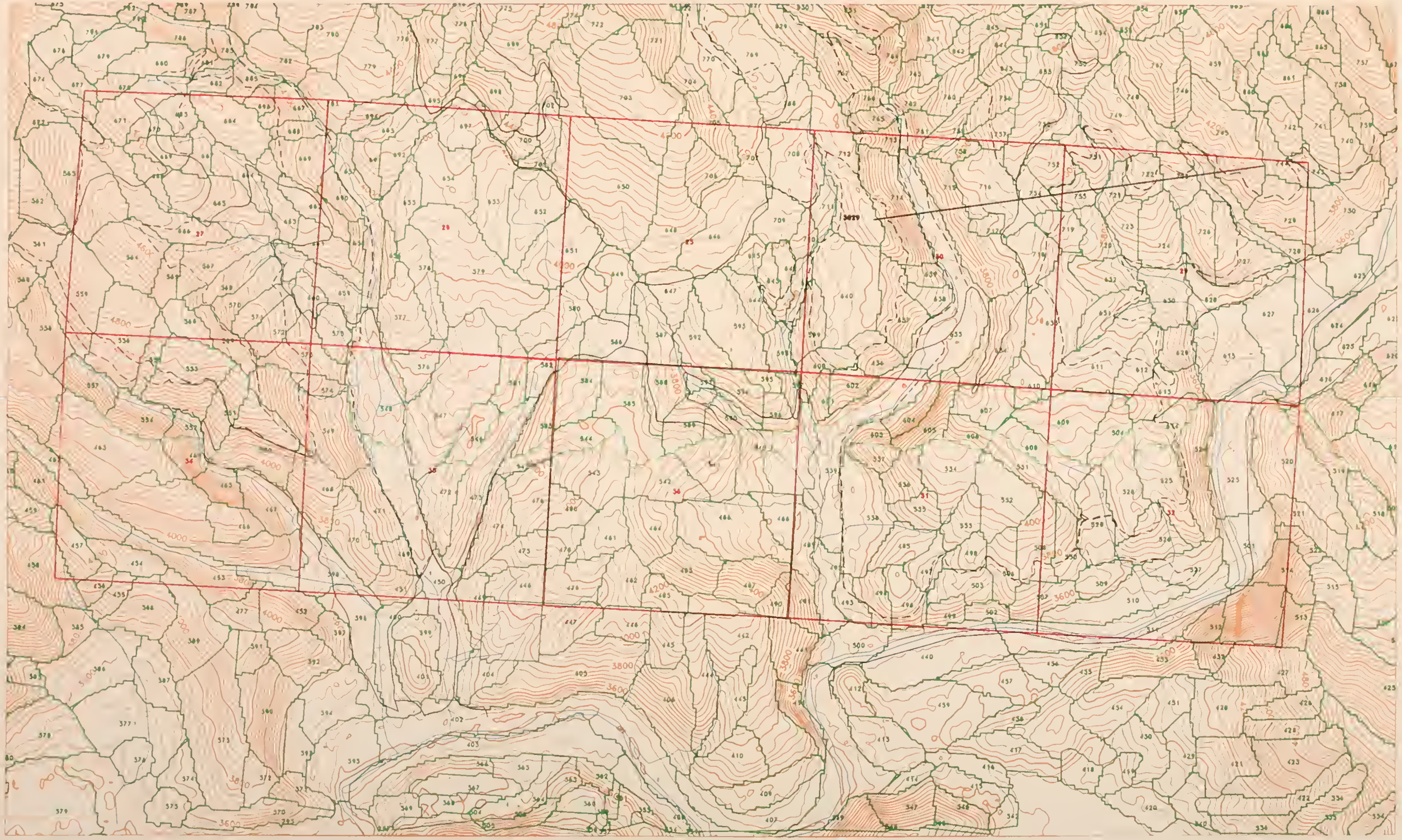
FIGURE 11 PHOTO COMPOSITE

SUNFLOWER MTN DEM 7 1/2 , MT
DOCUMENT NUMBER 6314 IS A PHOTO OF F/L = 305.47



TIME 19 28 MST, 01/05/83.
PRODUCT OF U.S.F.S. DIGITAL TERRAIN INFORMATION SYSTEM

FIGURE 12 TOPOGRAPHIC COMPOSITE MAP



SUNFLOWER MTN DEM 7 1/2 , MT
DOCUMENT NUMBER 15840 IS A MAP OF SCALE 1320 FT/IN.
TIME 18 34 MST, 09/20/82.
PRODUCT OF U.S.F.S. DIGITAL TERRAIN INFORMATION SYSTEM

N

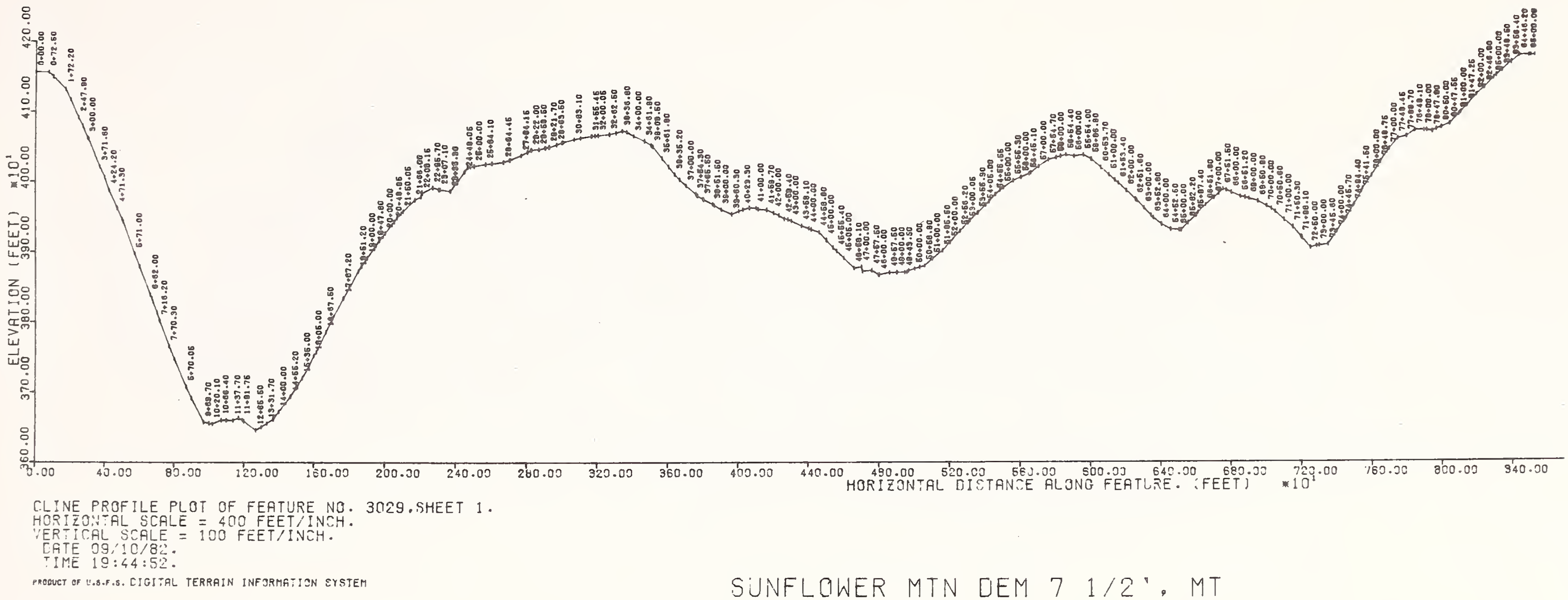


FIGURE 13 CROSS SECTIONAL PROFILE

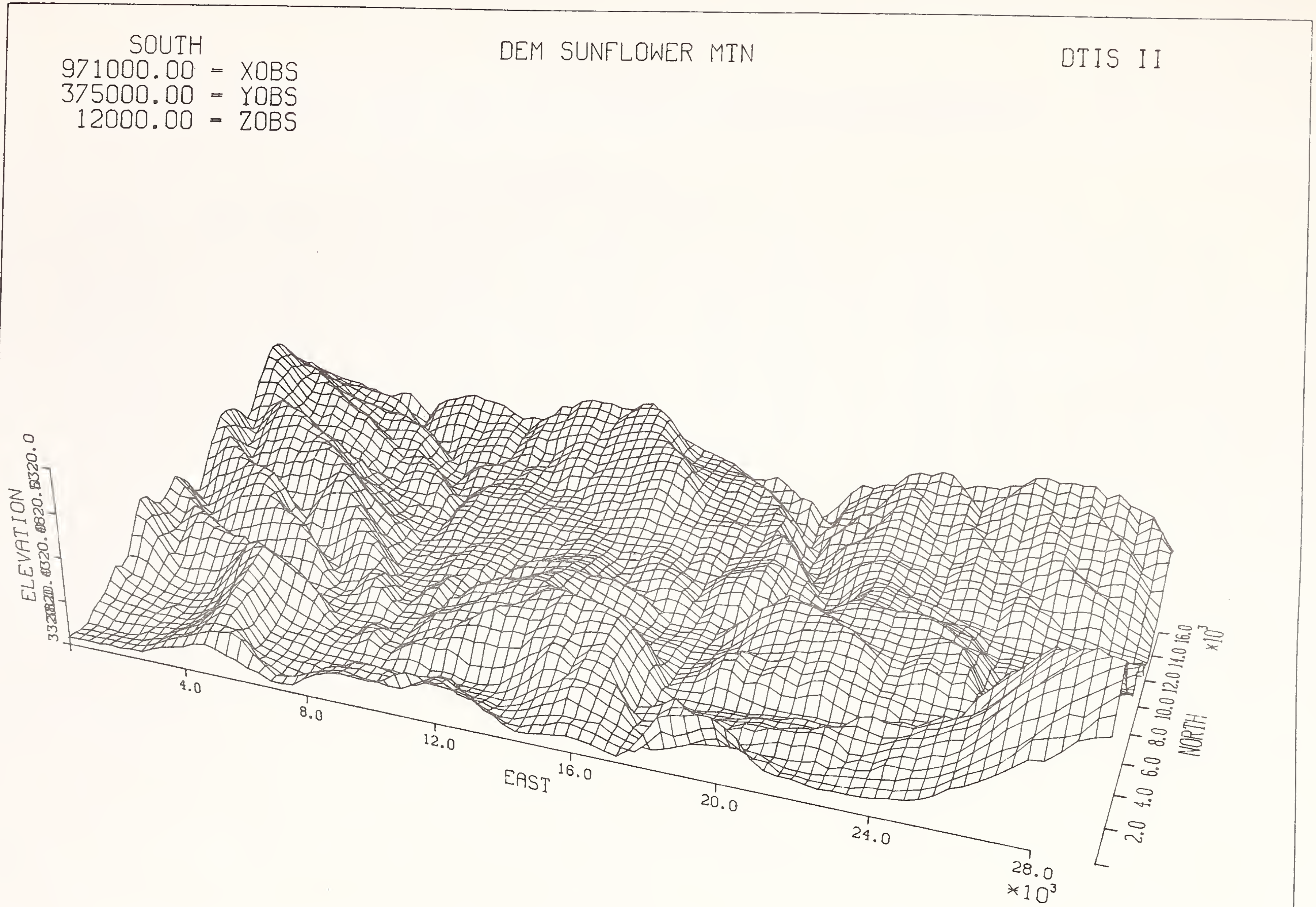


FIGURE 14 OBLIQUE PERSPECTIVE

FIGURE 15 SYSTEM 2000 OUTPUT LISTING FOREST STAND CHARACTERISTICS

STAND DATA FOR SUNFLOWER MTN
10/15/1982

* QUADNAME	FLU#	PATT ERN	TEXT URE	CANC OVER	HIGH	CRWN SIZE	MODI FIER	ASPE CT	SLOP	POSI TION	ELEVA	OWN ER	PIFO RTYP	ACRES	VOLUM BFS	VOLUM FT3
***																
* SUNFLOWER MT	334	V BR	M FI	~ 25	60-8	16-2	NONE	SE	46-6	MIDS	4478	PRIV	P PI	14	1318	272
N		OKEN	NE	%	9FT	4FT			5%	LOPE		ATE	NE			
* SUNFLOWER MT	336	V BR	M FI	~ 25	60-8	16-2	NONE	S	66-8	MIDS	4421	PRIV	P PI	21	1318	272
N		OKEN	NE	%	9FT	4FT			5%	LOPE		ATE	NE			
* SUNFLOWER MT	339	V BR	M FI	25-4	60-8	6-15	NONE	S	46-6	MIDS	3805	PRIV	DOUG	20	2804	483
N		OKEN	NE	9%	9FT	FT			5%	LOPE		ATE	-FIR			
* SUNFLOWER MT	340	MOTT	M FI	70-8	60-8	6-15	NONE	S	36-4	MIDS	3583	PRIV	DOUG	24	4283	1529
N		LED	NE	0%	9FT	FT			5%	LOPE		ATE	-FIR			
* SUNFLOWER MT	342	V BR	M FI	50-6	30-5	6-15	NONE	E	16-2	MIDS	3519	PRIV	DOUG	11	2454	611
N		OKEN	NE	9%	9FT	FT			5%	LOPE		ATE	-FIR			
* SUNFLOWER MT	346	V BR	M CO	50-6	60-8	16-2	NONE	N	66-8	MIDS	3717	PRIV	DOUG	16	5467	1176
N		OKEN	ARSE	9%	9FT	4FT			5%	LOPE		ATE	-FIR			
* SUNFLOWER MT	347	UNIF	M CO	" 80	90-1	25-4	NONE	N	66-8	MIDS	3828	PRIV	MXUP	27	16149	3514
N		ORM	ARSE	%	20FT	0FT			5%	LOPE		ATE	CONF			
* SUNFLOWER MT	360	V BR	M FI	25-4	60-8	16-2	LOGG	N	6-15	MIDS	3665	PRIV	DOUG	11	2991	537
N		OKEN	NE	9%	9FT	4FT	ED		%	LOPE		ATE	-FIR			
* SUNFLOWER MT	361	MOTT	M FI	70-8	60-8	6-15	NONE	N	46-6	M DR	3436	PRIV	MXUP	5	4283	1545
N		LED	NE	0%	9FT	FT			5%	AIN		ATE	CONF			
* SUNFLOWER MT	362	V BR	M FI	25-4	60-8	16-2	NONE	N	66-8	MIDS	3466	PRIV	DOUG	9	2991	537
N		OKEN	NE	9%	9FT	4FT			5%	LOPE		ATE	-FIR			
* SUNFLOWER MT	363	UNIF	M FI	" 80	60-8	16-2	NONE	NW	36-4	MIDS	3611	PRIV	DOUG	9	6909	2270
N		ORM	NE	%	9FT	4FT			5%	LOPE		ATE	-FIR			

PREPARED BY FRED MARTIN MT FOR. & CONS. EXP. STA.

VI. CONCLUSIONS

CONCLUSIONS

The programs and techniques described are fully operational and have been applied to varying degrees on 1.5 million acres in western Montana. The computer programs used, RID*POLY and DTIS II, have been extensively tested and are currently supported by national programs within the Forest Service. These systems are written in FORTRAN and are Government-produced computer programs.

The methods employed in this study were initially envisioned for large area applicability but have proven useful and efficient for smaller areas, including the 32,000 acre Lubrecht State Experimental Forest, a coordinated planning project near Missoula, a smaller 6,000 acre industrial forest management area, and a National Forest and private land exchange proposal. Resource scale photography (1:12,000) has proven to be just as usable as 1:80,000 scale photography. The main difference being the need to handle and control a larger number of photographs.

The principal advantage of automated methods is the ability to quickly and economically aggregate photointerpreted information and to output this information in numerous formats. This advantage is achieved through rapid digitizing of graphical data and automated photo-to-map transfer. The photo-interpretation, preparation of the scribe coat suitable for electronic scanning and the editing of the scanner data are the most labor intensive steps in this "automated" mapping system. However, the generally accepted notion that electronic scanning of graphic documents is plagued with problems did not materialize in this project. The apparent key to this success is having quality input documents.

The automated photo-to-map transfer of photointerpreted data was also performed with surprising ease.

Although rapid digitizing and automated photo-to-map transfer enables the efficient mapping of photointerpreted data, the most beneficial aspect of this process is the development of an integrated geographic information system. Because DTIS II converts all input into X, Y, and Z ground coordinates for internal storage, graphic inputs from different sources can be integrated. In this study, ownership and jurisdictional boundaries from 7.5-minute quadrangle maps were integrated with FLU's delineated from 1:80,000 scale photographs. Roads and streams from the 7.5-minute quadrangle, and new roads digitized from 1:12,000 scale aerial photographs were added. Photogrammetric control points derived from both ground survey and aerial triangulation, as well as terrain model data were also incorporated into the same data base. Figures 11 and 12 illustrate this integration capability.

An integrated management information system and geographic information system can also provide a means for updating and coordinating land management activities. Attribute changes, such as forest depletions can be made in the management system and new volume maps generated by the geographic system. As new photography is acquired, changes in stand boundaries can be identified, such as those resulting from logging or fire, and the management system updated from the geographic system.

The relationships analyzed between PI characteristics and ground attributes showed that a strong correlation exists for predicting timber volume. Other variables, including yield capability as an estimate of prime forest land, proved to be less predictable. Habitat type was the least predictable of all the ground attributes tested.

The report describes many benefits of using computer assisted mapping techniques. However, three distinct difficulties were noted during the course of the study. First, use of computer techniques requires access to specialized equipment. Electronic scanners, main-frame computers and computer controlled plotters, and photogrammetric control data are required. Second, a substantial amount of planning is necessary. Although these processes require less total time overall than traditional manual methods, long lead times are required to complete the numerous separate operations. Also, because the computer systems used (RID*POLY, DTIS II, System 2000, etc.) are not formally integrated, a high degree of managerial control is essential.

The total cost for developing the components of this system over the past 3 years was $209,400 of which $150,000 is estimated to have been direct project related after removing overhead. The net amount of land processed by the system during this period is approximately 1.5 million acres. The resulting direct development cost experience with this system was therefore about 10 cents per acre. An approximate breakdown of this cost into major system phases is as follows:

Photo interpretation	$50,000	3.5¢/Acre
Map system	60,000	4
Statistical analysis	40,000	2.5
	$150,000	10.0¢/Acre

The following specific costs or person hour estimates were incurred in this study and should be viewed as approximations for items of work.

.Stereo pair high resolution diapositives of 1:80,000 aerial photo	$10 each
.7.5-minute topographic quad	$1 each
.Manual digitizing and editing landownership, jurisdictional and quad boundaries	4 hours each
.Developing a DTIS II project system file for a 7.5-minute topographic quadrangle	
-- DMA terrain model	$2 each
or USGS DEM terrain model	$100 each
-- Photogrammetric control for a 1:80,000 photo	$10 each
-- Loading terrain model, photo control and digitized ownership boundaries into DTIS II to develop photo collar	4 hours each

•Photo interpretation of the 7.5-minute quad collar portion of the 1:80,000 aerial photo (contract)	$600 each
•Scribing the delineated FLU polygons onto a scribe coat (average 1500 FLU's per photo collar)	8 hours each
•Electronic scanning of scribe coat	0.5 hours each
•Edit of the scanner data and polygon extraction	8 hours each
•Enter scan data into computer and output plot	2-4 hours each
•Computer Costs	
-- Processing scanner data	$150 each
-- Creating DTIS II system file	$80-100 each
-- Creating map plots	$10 each

VII. OPPORTUNITIES

OPPORTUNITIES

The computer assisted forest land mapping and inventory techniques presented in this report provide a capability for improving the accuracy and timeliness of inventorying and analyzing forest resources over existing systems at less cost.

Timber was the primary resource studied. The techniques developed are applicable for extending extensive forest inventories into detailed mapped Forest Land Units. The computer stored data can be updated easily. Land managers can access this system for timber sale layout. Timber stand volumes can be predicted with considerable reliability thereby enabling the location of harvesting opportunities. Alternative road locations can also be computer located and various designs analyzed. Visual quality effects from potential cutblocks can be evaluated using perspective views from any vantage point. The systems capability to draw geographic information onto aerial photographs presents new analyses opportunities to the land manager. Location of landownership boundaries onto aerial photographs will help prevent timber trespass and also identify existing trespasses. The automated transfer of proposed timber cutting boundaries and roads from maps to aerial photographs can assist the timber manager in field reconnaissance of proposed timber sales.

The prediction of site index, growth, stocking and crown competition proved less reliable. However, through further evaluation, the reliability may be improved to where timber stand improvements, reforestation and other investment opportunities could be computer identified and mapped. Prime timberland could also be located through the system.

A County or State-wide forest land inventory developed on this system would enable the State service forestry organization to evaluate and prioritize where and what kind of assistance could be provided to the private landowner. The data would also be useful in developing or updating Federal, State, and County resource plans and as initial interpretations for private landowner management plans.

The versatility of this system enables other combinations of landform and forest vegetative characteristics to be extracted which may be of value in evaluating other resource problems or opportunities such as wildlife habitat capability, fire hazard, insect or disease infestation potential, erosion and sediment potential, water yield and recreation development.

There is an opportunity on the part of several of the larger forest landowners in Missoula County to verify the volume equations presented in this report.

--Montana Department of Lands has an opportunity to test the equations on Section 36, Township 11 North, Range 19 West, where 48 ground plots placed on an 8-chain by 8-chain grid were recently completed on the three-quarter section of State land.

--Burlington Northern Incorporated also has an opportunity to test the equations on Section 3, Township 12 North, Range 23 West, where 64 ground plots placed on an 8-chain by 8-chain grid were recently completed on this section of their land.

--Champion International Corporation has an opportunity on nine sections of its land in the Blackfoot area where numerous ground plots have already been taken and are shared cooperatively with the University of Montana School of Forestry.

--Montana Forest and Conservation Experiment Station has an opportunity on the entire Lubrecht Experimental Forest with years of measurements taken on the ground.

--Lolo National Forest has an opportunity on its Ninemile and Superior Ranger Districts wherever it has established growth plots and completed stand examinations.

--Most other private landowners in Missoula and Mineral Counties could also participate in the verification should they be in a position of having recent ground measurements.

In all cases where verification is attempted it is essential that measurements be expanded with the same volume procedures to which the volume prediction equations are fitted.

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APPENDIX

APPENDIX

FLU DESCRIPTION CRITERIA AND CODING FORMAT

ELEMENT	CODE	CARD COLUMNS
I. FLU, Federal, or non-Forest polygon number		1-4
1. FLU (sequential number starting at 1)	#	
2. Federal (sequential number preceded by F, starting at 1)	F#	
3. Non-Forest (sequential number preceded by N, starting at 1)	N#	
II. Photographic Pattern (Distribution of Trees)*		5
1. Uniform	1	
2. Mottled	2	
3. Partially Broken	3	
4. Very Broken	4	
III. Photographic Texture of Overstory*		6
1. Coarse	1	
2. Medium Coarse	2	
3. Medium Fine	3	
4. Fine	4	
IV. Crown Canopy Coverage*		7
1. >80 percent	1	
2. 70 - 80 percent	2	
3. 50 - 69 percent	3	
4. 25 - 49 percent	4	
5. <25 percent	5	

*These are actual delineation criteria used to differentiate FLU's. All other elements are used only to describe or characterize an FLU.

ELEMENT	CODE	CARD COLUMNS
(Note: Stands with less than 10 percent natural crown canopy coverage are non-Forest)		
V. Average Stand Height*		8
1. >120'	1	
2. 90 - 120'	2	
3. 60 - 89'	3	
4. 30 - 59'	4	
5. <30'	5	
VI. Average Crown Size*		9
1. >40' (.006")	1	
2. 25 - 40' (.004 - .006")	2	
3. 16 - 24' (.0025 - .004")	3	
4. 6 - 15' (.001 - .0025")	4	
5. <6' (.001")	5	
(Note: Number in parentheses are crown sizes at 1:76,000 photo scale.)		
VII. Land or Vegetation Modifier*		10-11
1. None	1	
2. Logged	2	
3. Undetermined disturbance	3	
4. Hardwoods - 20 - 49 percent crown canopy coverage	4	
5. Hardwoods - >50 percent crown canopy coverage	5	
6. Rocky Surface (>50 percent of surface is obviously rock covered)	6	
7. Mass failure	7	
8. Swampy or wet bottom (standing water evident)	8	

*These are actual delineation criteria used to differentiate FLU's. All other elements are used only to describe or characterize an FLU.

ELEMENT	CODE	CARD COLUMNS
9. Two-storied stand (at least one stand height category between upper and lower stories, at least 30' difference)	9	
VIII. Topographic Exposure (Aspect)*		12
1. FLAT (<5 percent slope angle)	1	
2. 337.5° - 22.5° (N)	2	
3. 22.6° - 67.5° (NE)	3	
4. 67.6° - 112.5° (E)	4	
5. 112.6° - 157.5° (SE)	5	
6. 157.6° - 202.5° (S)	6	
7. 202.6° - 247.5° (SW)	7	
8. 247.6° - 292.5° (W)	8	
9. 292.6° - 337.5° (NW)	9	
IX. Slope Angle*		13
1. 0 - 5 percent	1	
2. 6 - 15 percent	2	
3. 16 - 25 percent	3	
4. 26 - 35 percent	4	
5. 36 - 45 percent	5	
6. 46 - 65 percent	6	
7. 66 - 85 percent	7	
8. >85 percent	8	
X. Topographic Position*		14
1. Talweg (valley bottoms and generally sloping, <10 percent, hydrologically active areas)	1	
2. Midslope drain	2	
3. Midslopes	3	

*These are actual delineation criteria used to differentiate FLU's. All other elements are used only to describe or characterize an FLU.

ELEMENT	CODE	CARD COLUMNS
4. Midslope ridge		
5. Interfluve (major divides with gentle slopes, <10 percent)	5	
XI. Contour Curvature*		15
1. Concave Rh = >-500m (>-.25")	1	
2. Undulating	2	
3. Straight Rh = >500m to <-500m	3	
4. Convex Rh = <+500m (<.25")	4	
5. Zigzag	5	

(Note: Rh = Radius of horizontal curvature; numbers in parentheses are at photo scale)

ELEMENT	CODE	CARD COLUMNS
XII. Elevation		16-17
1. 1,500 - 2,000'	1	
2. 2,001 - 2,500'	2	
3. 2,501 - 3,000'	3	
4. 3,001 - 3,500'	4	
5. 3,501 - 4,000'	5	
6. 4,001 - 4,500'	6	
7. 4,501 - 5,000'	7	
8. 5,001 - 5,500'	8	
9. 5,501 - 6,000'	9	
10. 6,001 - 6,500'	10	
11. 6,501 - 7,000'	11	
12. 7,001 - 7,500'	12	
13. 7,501 - 8,000'	13	
14. 8,001 - 8,500'	14	
15. 8,501 - 9,000'	15	

*These are actual delineation criteria used to differentiate FLU's. All other elements are used only to describe or characterize an FLU.

ELEMENT	CODE	CARD COLUMNS
16. 9,001 - 9,500'	16	
17. 9,501 - 10,000'	17	
18. >10,000'	18	
XIII. Average Precipitation		18-19
1. 10 - 19	1	
2. 20 - 29	2	
3. 30 - 39	3	
4. 40 - 49	4	
5. 50 - 59	5	
6. 60 - 69	6	
7. 70 - 79	7	
8. 80 - 89	8	
9. 90 - 99	9	
10. 100 - 120	10	
11. >120	11	
XIV. County Location		20-22
Three digit code from listing		
XV. Ownership Status		23
1. State	1	
2. Private	2	
XVI. River Basin Location		24-26
A. Kootenai River Basin		
1. Kootenai River	101	
2. Fisher River	102	
3. Yaak River	103	
4. Lower Kootenai River	104	
5. Moyie River	105	

ELEMENT	CODE	CARD COLUMNS
B. Clark Fork River Basin		
1. Upper Clark Fork River	201	
2. Rock Creek - Willow Creek	202	
3. Blackfoot River	203	
4. Middle Clark Fork River	204	
5. Bitterroot River	205	
6. North Fork Flathead River	206	
7. Middle Fork Flathead River	207	
8. Flathead Lake	208	
9. South Fork Flathead River	209	
10. Stillwater River	210	
11. Swan River	211	
12. Lower Flathead River	212	
13. Lower Clark Fork River	213	
XVII. Forest Type		27
1. Ponderosa pine (MFS Type 11)	1	
2. Douglas-fir (MFS Type 01)	2	
3. Mixed upland conifer (MFS types 21, 33, 36, 54, 55, 56, 57)	3	
4. Mixed bottomland conifers (MFS types 35, 41, 48)	4	
5. Lodgepole pine (MFS type 61)	5	
6. Mixed hardwoods (MFS types 83, 85)	6	
7. Whitebark/Limber pine (MFS type 96)	7	
8. Undeterminable (no tree cover or immature stand development)	8	

GLOSSARY

Attribute - A term or phrase reflecting classification or description, i.e., a label.

Control point - A point on the ground of known or accurately determined horizontal and vertical position, i.e., latitude, longitude and elevation.

Coordinate - The linear or angular quantities which designate the position that a point occupies in a given reference frame or coordinate system.

Correlation coefficient (R) - A measure of the correlation between two or more random variables, which can take values from -1 to +1. A value near to +1 indicates almost perfect **positive** (= direct) **correlation**, a value near to -1 almost perfect **negative** (= inverse) **correlation**; a value near to zero indicates no correlation but not necessarily the independence of the variates. R^2 is equal to the correlation coefficient squared.

Crown competition factor - A measure of tree density, which in final form is similar to the tree-area ratio. The factor is an estimate of the area available to the average tree in the stand in relation to the maximum area it could use if it were open grown.

Digitize - To use numbers to represent data, e.g., representation of a graphic line as a string of XY coordinates or a series of grid cell locations.

Digital Terrain Information System (DTIS) - A system of computer programs that provide for the collection, analysis and display of digitized data, with principal focus on terrain data. DTIS was developed and is currently maintained by the U.S. Forest Service Engineering Geometronics staff in Washington, D.C.

Discriminate analysis - A term used to describe the statistical methods used in problems of classification. Given that an individual may belong to one of a number of populations, such analyses allocate it to the correct population with minimum error, generally on the basis of multiple measurements of the individual and a prior set of similar measurements on individuals whose origin is known.

"F" test - A comparison of means of different sets of data to determine the likelihood of the sets representing the same population or different populations.

Forest Land Unit - A delineation of a forested tract of land possessing similar vegetation overstory characteristics and similar topographic characteristics.

FORTRAN - An international source--programing language created for mathematical and other scientific problems, the computing instructions of which are expressed in a modified algebraic notation.

Geographic feature - A characteristic of the earth's surface.

Geographic information system - A system of computer programs that provide for the collection, analysis and display of digitized data. Principal focus is normally on the ability to automatically generate a new map from a combination of two or more existing maps, i.e., overlay processing.

Grid map - A plane network of lines, formed by two parallel sets intersecting at right angles, with one set ∥ to true north at some specific point, which is imposed on a map for purposes of location, the lines or the rectangles they enclose being serially numbered or lettered. NOTE: The position of any point within a grid may be represented by a pair of numbers (**grid co-ordinates**) whose values are the perpendicular distances of the point from two specified, intersecting grid lines.

International volume - A measurement of tree volume in board feet of lumber using a formula log rule which allows one-half inch tapes for each 4-foot of length and one-sixteenth inch shrinkage for each lineal board.

Montana forest survey - A renewable resource evaluation conducted periodically by the Intermountain Forest and Range Experiment Station and the Montana Division of Forestry.

Oblique perspective - The photographic view resulting from a perspective projection, when the camera axis is intentionally directed between the local vertical and local horizontal.

Photointerpretation - The detection, identification, description, and assessment of the significance of objects and patterns imaged on a photograph.

Photo perspective - The photographic view resulting from the projection of ground points through a lens to the photographic emulsion. Mathematically, the resulting projection is referred to as a perspective projection.

Photogrammetric control - A series of points of known position that are required to fix the attitude and/or position of a photograph or group of photographs in order to map photographic features.

Photo collar - A computer generated plot showing the location of a 7.5-minute quadrangle and other boundaries drawn in the perspective of an aerial photograph with appropriate compensation for topographic relief displacement.

Quad-centered photography - A vertical photograph whose center is coincident with the center of a 1:24,000 7.5-minute quadrangle map.

Regression analysis - the relationship between specified values of one or more variables (termed the **independent variable**) and the expectation of a random variable (the **dependent variable**) whose distribution depends on the particular values taken on by the independent variable(s); generally expressed as a **regression equation**.

RID*POLY - A system of programs that accept raster scan or polygon encoded digitized data. Its' counterpart, RID*GRID, accepts grid cell encoded digitized data. Collectively, both systems are referred to as RIDS, an acronym for Resource Information Display System. Both support several

analysis and display options, including overlay processing. RIDS maintenance is supported at the National level, by U.S. Forest Service Engineering, Geometronics.

Scribe coat - A material commonly used in mapping consisting of two layers. The base layer is transparent. The second layer referred to as the scribe coat is opaque. The opaque layer when scratched with a sharp instrument (a scribe pen), is easily removed.

Spatial data - A term descriptive of the two-dimensional (XY) or three-dimensional (XYZ) location of features in space.

Scanner matrix - Data output from a scanner in raster (row/column) format. Each data element (pixel or cell) contains a number representing a measure of density, reflectance or transmission, the specific measure depending on the type of scanner.

Scatter plot - A two-dimensional graph of data points where the coordinator of the points are the values of the two variables being considered. One variable defines the vertical axis and the other variable defines the horizontal axis.

Scribner volume - A measurement of tree volume in board feet of lumber using a diagram log rule which assumes one-inch boards and a one-quarter inch saw kerf, makes a liberal allowance for slabs and disregards taper.

State plane coordinate - A system developed by the U.S. Coast and Geodetic Survey in the 1930's to provide rectangular coordinates for survey reference. This system consists of 111 different zones of projection for the conterminous United States. Since the early 1950's, the USGS 7.5-minute and 15-minute map series have been constructed on the SPC projections. Within any one zone, all map sheets can be fitted together without gaps or discontinuities.

Terrain model - A mechanical, optical or digital representation of terrain.

Transformation equation - When applied to photographic data, transformation normally refers to the process of projecting mathematically digitized feature data into another coordinate system by translation, rotation and/or scale change. Map features can be transformed to the photograph, as well as the more conventional transformation of photographic features to a map.

Yield capability - Also forest site productivity. A classification of forest land in terms of potential cubic-foot volume growth per acre of culmination of mean annual increment in fully stocked natural stands.